ORION -An Accelerator Research Facility At SLAC[*]

Introduction

Advanced accelerator research is crucial for the future of particle physics. The goal is to understand the physics and develop the technologies essential for reaching high energies. The importance of this goal has been recognized by the international community as evidenced by the increased number of scientific meetings on advanced accelerator concepts. Further, this research has appealed to scientists and others outside the traditional accelerator physics community thus broadening participation in the field. This brings the strengths of diverse intellectual inquiry and the energy and enthusiasm of university faculty and students. However, universities do not have the facilities and resources of the national laboratories. The ideal would be to combine the strengths of universities and national laboratories to allow rapid progress in this field.

This is a description of a facility for advanced accelerator research, based on the NLC Test Accelerator (NLCTA), which would attract scientists from universities and national laboratories with a passion for advanced accelerator research. The needed resources (electron beams, lasers, beam diagnostics, utilities, space, etc.) would be readily available and scientists from universities and other national laboratories would be welcome and able to participate in a meaningful way. This description includes an example of an experimental program.

A Facility Based On The NLCTA

The NLCTA would be the centerpiece. It consists of a 50 MeV injector followed by the main linac that has four 1.8 m long, X-band accelerating structures. The injector produces a 100 nsec long train of X-band bunches each with ~10^8 electrons. Approximate beam energies at the end of the injector and the end of the linac are 50 MeV and 300 MeV, respectively. The experimental program discussed in the next section uses beams at both energies. A 300 MeV beam for accelerator research would be unique in the world and essential for some experiments. A 50 MeV beam is not unique, but having both energies available at the same facility gives breadth to an experimental program and deals with an availability issue that must be solved for the facility to be attractive.

The primary role of the NLCTA is to support NLC development. The NLC development plans for the next three years call for extensive use of the RF equipment associated with the main linac. Much of this will be for power testing of prototype components. High energy beams might be possible for intervals, but the intervals are likely to be limited in number and duration. However, the injector will be largely unused for NLC development during that period and would be available for other uses.

A number of changes and additions are necessary for an NLCTA based advanced accelerator facility. These include:

- A low emittance, single (or few) bunch injector that would compliment the present 100 nsec long, ~1000 bunch, injector.
- A laser facility to drive this injector.
- A bypass of the injector chicane to avoid the emittance dilution associated with it.
- An experimental area at 50 MeV that would rely on beam from the injector.

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[*] Based on a report to the SLAC Faculty written by C. Adolphsen, M. Breidenbach, R. Byer , J. Clendenin, M. Hogan, D. Palmer, J. Rosenzweig, R. Ruth, and R. Siemann

- An extension of the NLCTA shielded area beyond the present dump for experiments at 300 MeV.

Details are presented following the discussions of the example experimental program.

An Experimental Program

An experimental program has been developed to illustrate possible experiments and learn the technical requirements on an NLCTA based accelerator research facility. Experiments are described briefly and, where appropriate, summarized in Table 1 included in this section.

High Frequency Power Generation: These experiments would study power production and high gradients in 22.8, 34 and 92 GHz structures. The 22.8 and 34 GHz experiments would study gradients up to about 200 MeV/m to establish the viability of ideas for two-beam accelerators. The 92 GHz work would be a continuation of recent experiments that have produced 150 kW of W-band power. A 2 Amp, 100 nsec long pulse with X-band bunch structure is required. Fifty MeV is appropriate for initial tests of short, 22.8 and 34 GHz structures, and 300 MeV is needed for longer structures and for adiabatic damping to reduce emittance sufficiently to fit into the apertures of 92 GHz structures.

RF Photocathode Sources And Emittance Compensation: The production of high peak current, high brightness beams is a research topic of importance for linac based light sources and linear colliders. RF photocathode guns and other high-brightness sources require acceleration to more than 20 MeV to permit emittance compensation and to reduce space charge effects sufficiently to allow measurement of beam properties. In many cases energy greater than 100 MeV is necessary. Space along the beamline and adequate shielding is required.

A high brightness, high charge X-band photocathode gun would be a forefront R&D project that would extend sources to high frequencies. In addition, this source would be necessary for accelerator experiments that require a single, or a few, bunches. At even higher frequencies W-band power developed in a relativistic klystron configuration could be used as the power source for a W-band RF gun.

Laser Acceleration: A single cell, laser driven dielectric accelerator is being studied on the Stanford campus in a proof-of-principle experiment. The next steps include multiple cells, structure design, and integration of the accelerator and drive laser. These experiments require a single pulse 50 MeV beam with low charge, short bunch length, and low emittance.

Coherent Synchrotron Radiation: Coherent synchrotron radiation causes emittance dilution and is an important consideration in the design of accelerators producing high peak current, high brightness beams. There is little experimental data on this phenomenon because space charge effects dominate low energy measurements. Measurements at 300 MeV would be the definitive study of coherent synchrotron radiation. A high brightness, high current RF photoinjector is required.

Single Bunch Dipole Signal Measurements: The X-Band accelerator structures being developed for the NLC include a system of waveguides that couple out the dipole mode (14 GHz to 16 GHz) energy that is deposited when a beam traverses the structures off-axis. These waveguides serve both to damp the dipole mode excitations and to provide a signal that can be used as a guide to center the beam within the structure. This beam centering approach will be crucial for maintaining the small beam emittances in the NLC.

Table 1: An Experimental Program

Experiment	Bunch Structure	Energy (MeV)	Comments/Critical Parameters
Two-Beam Acceleration (22.8 & 34 GHz Structures)	2 A, 100 nsec long pulse	50, 300	
W-Band Power Production	2 A, 100 nsec long pulse	300	
High Brightness Sources & Emittance Compensation)	Single Bunch, 1 nC	50, 300	Low emittance (1-2$\times$10^{-6} m), High peak current beam
Laser Acceleration	Single Bunch, 0.002 - 0.002 nC	50	Modest emittance (~10^{-5} m), 1-2 psec pulse length, 0.10% energy spread
Coherent Synchrotron Radiation	Single Bunch, 1 nC	300	Low emittance (1-2$\times$10^{-6} m), High peak current beam
Single Bunch Wakefield Measurements	Single Bunch, 1 Nc	300	
Polarimeter Development	Variety	50, 300	Polarimeter used to measure polarization for a variety of sources
Plasma Acceleration	Two Bunches, 1 Shaped to Drive Plasma Wave	50, 300	The second, low intensity bunch measures the wakefield. Time between bunches adjustable
Instrumentation	Variety	50, 300	

Thus far, beam centering tests have been done in the ASSET facility in Sector 2 of the SLAC Linac. Because there is limited access to this facility, it would be useful to have another test beam. The present beam at the NLCTA does not significantly excite the structure dipole modes since the Fourier component of the beam current in the 14-16 GHz range is very small. Providing a single-bunch source of about 10^{10} electrons would allow some testing at the NLCTA. The dipole signal processing methods and hardware could be developed although the wakefields could not be directly measured as is done with two beams in ASSET.

Another NLC related activity would be to design and test a gun and laser system that could produce the NLC pulse pattern. This would be a research project outside the scope of the facility.

Photocathode And Polarimeter Development: Some photocathode development for advances in high-brightness and polarized beams could be done in other SLAC facilities, but there are two critical roles for an accelerator research facility. The first is demonstration of an emittance compensated RF gun configuration which requires acceleration to 20 MeV or more.

The second is the development and subsequent use of an online polarimeter. The beam must be accelerated to ~100 MeV in future e^+e^- collider designs because there is no space for a polarimeter at lower energies.

Plasma Acceleration: The basic configuration of a plasma accelerator is a (laser or particle) drive beam exciting a plasma wave and a trailing particle beam being accelerated by that wave. A particle drive beam is the natural one for an initial program since it avoids the problem of laser diffraction. Fundamental acceleration theorems that relate the drive beam charge distribution and the maximum possible energy gain could be tested by shaping the laser pulse that drives the RF gun. A second bunch would be used to measure acceleration.

Accelerator Instrumentation: Beams could be used for a wide variety of instrumentation development. Examples include laser wires for profile and bunch length measurements and electro-optical crystals for bunch length measurement.

This is a possible program. There are a variety of other experiments that could be part of the initial program or could be follow-on or second generation experiments. These include an NLC injector prototype, femtosecond x-ray production by Compton scattering, and a multi-beam acceleration experiment to test the matrix accelerator concept. There are potential activities using positrons including an experimental area for positron channeling studies and a polarized e^+ source produced using a 100 MeV polarized electron beam. Space would have to be reserved for a positron target vault in the facility layout. Finally, the linac could be used as the low emittance injector to a Laser Electron Storage Ring in which an electron beam in a very small storage ring interacts with a laser pulse stored in a resonant cavity to produce even smaller emittances than those envisioned for the NLC.

Details Of An NLCTA Based Facility

A number of changes and additions to the NLCTA are required. They were enumerated above, and this section contains details. It also includes a cost estimate.

The facility is shown in Figures 1 and 2. It consists of two experimental halls and two laser rooms. The lower energy experimental hall is for 50 MeV beams produced by the injector, and it has room for three experimental beam lines. The higher energy hall is an extension of the present NLCTA enclosure and is intended for 300 MeV beams. The figures also show the footprint of a larger high energy hall that was eliminated from the initial plans to save money. This potential use of Research Yard space should be considered as utilization changes during the retrofitting for earthquake safety and to accommodate the LCLS. This layout is consistent with the anticipated additional NLC space needs in End Station B.

A high brightness, high peak current single bunch injector is needed for many of the experiments, and the present 100 nsec long pulsed injector is needed for NLC development and for some of the experiments. Some initial beam dynamics studies have been performed, and they indicate a 1 nC bunch with emittance $\sim 2\times 10^{-6}$ m could be achievable. The single pulse injector must be one the linac axis, and the chicane after the injector must be bypassed. Both are necessary to avoid emittance dilution.

The present injector would be put off-axis in a Y-configuration. It remains to be seen whether or not this can fit into the present enclosure or if the enclosure would have to be enlarged on the North side in the injector region.

There are two possible ways to bypass the chicane. One would be to mount it on a girder structure that could be removed and reinstalled precisely. The optics that replaced the chicane would also be mounted on a girder that could easily be installed and removed. The other option is to modify or replace chicane magnets so a straight ahead beam could be accommodated.

Electron beam diagnostics would consist largely of standard SLAC instrumentation for beam position monitors, wire scanners, and toroids. Optical diagnostics relying on transition radiation or Cerenkov radiation would be viewed by a streak camera, which we already own, or by 12- and 16-bit CCD cameras. Electro-optical techniques to measure relative electron beam to laser beam timing would be a valuable diagnostic once we have mastered the technique.

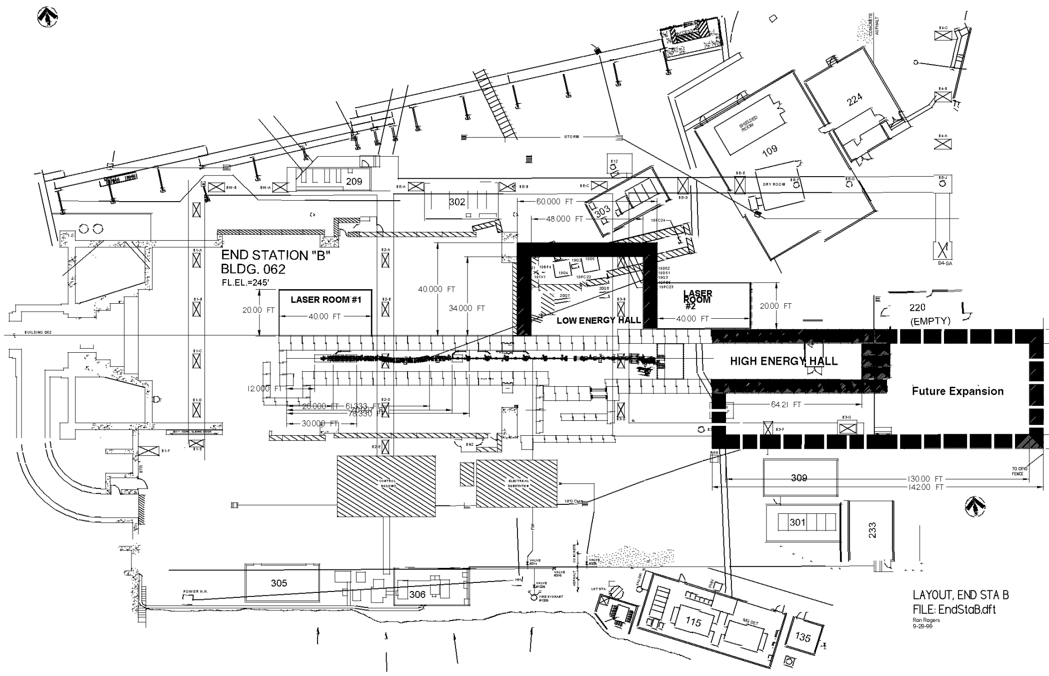

Figure 1: The NLCTA with the Accelerator Research Facility added. The facility consists of a Low Energy Hall, a High Energy Hall, and two laser rooms. The plan would be to initially extend the NLCTA tunnel to make space available for experiments and leave the full-sized High Energy Hall as a later option.

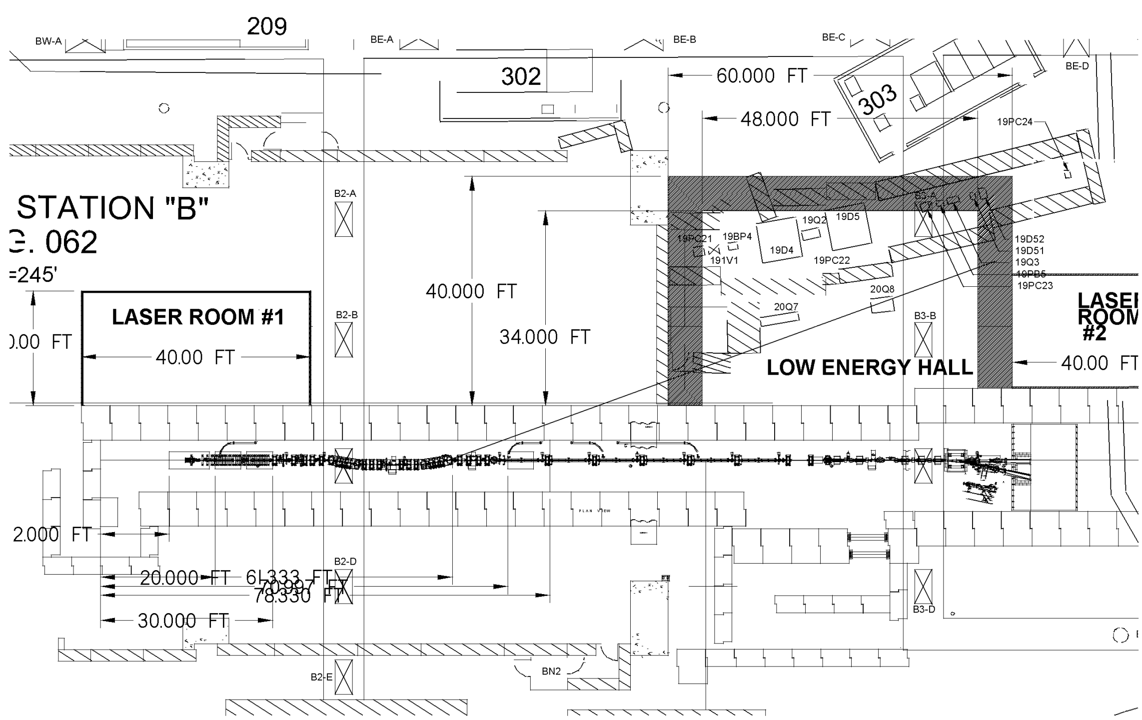

Figure 2: An expanded view showing the NLCTA and the extraction point for the Low Energy Hall.

The laser is a Ti:Sapphire system. A Ti:Sapphire oscillator is locked to the RF with commercial "lock-to-clock" electronics. The oscillator drives a Ti:Sapphire regenerative amplifier that produces 10 mJ energy in pulses as short as 130 fsec. The regenerative amplifier output is tripled giving approximately 500 µJ in the UV that is needed for producing 1 nC bunches from an RF gun with a copper photocathode. There is instrumentation for measuring pulse length, a single shot autocorrelator, and for steering and monitoring the laser beam.

A portion of the oscillator light will be transported to the second laser room where it could be used for driving a second regenerative amplifier that could be used for experiments.

A rough, preliminary cost estimate of $3.6 M for the facility has been developed with a number of assumptions.

- The project is managed by physicists intent on minimizing costs.
- Engineering is covered in the management costs, and existing SLAC designs are used wherever possible to allow building from existing drawings.
- The High Energy Hall is an extension of the NLCTA shielding, and the NLCTA infrastructure for cooling water, fire protection, personnel protection, etc. can be extended into the High Energy Hall.
- The AC power is available from the NLCTA substation and cooling water is available from the Research Yard.
- There are no beam lines and experimental equipment in the experimental halls, but there are appropriate utilities for them.
- There is no laser equipment in Laser Room #2.
- Nothing is scrounged from existing equipment, beamlines, etc.
- The estimate does not include contingency or indirects.

The costs were derived in part from NLCTA costs, in part from standard estimators adjusting for Bay Area costs, in part from estimates from commercial suppliers, and in part from estimates made by SLAC and SSRL engineers.

The essential elements of this facility for meaningful experimental program to start are the Low Energy Hall, the High Energy Hall, Laser Room 1, the single bunch injector, and the chicane bypass. Laser Room 2 and the extension of the High Energy Hall could be postponed until the experimental program has developed and their value becomes clear.

User Participation

SLAC is interested in establishing an advanced accelerator research facility as a user facility. Significant user participation in accelerator research at SLAC is well-established with numerous examples. The first is the Final Focus Test Beam (FFTB). BINP, DESY, KEK, and Orsay provided essential equipment including magnets and beam spot size monitors, and they were critical in commissioning, operating, and analyzing the experimental results. The second example was a study of photon-electron interactions in the parameter regime of future linear colliders performed in the FFTB by a Princeton, Rochester, SLAC, Tennessee collaboration (E-144). The third and fourth examples are the plasma lens (E-150) and plasma acceleration (E-157) experiments currently taking data. Physicists from Fermilab, KEK, LBNL, LLNL, Rochester, UCLA, and USC are providing essential apparatus including lasers, plasma cells and diagnostics, and they have been critical in every aspect of these experiments starting from the initial discussions leading to the proposals through the data taking and analysis.

The experimental program and NLCTA facility discussed above have the potential of significant interest outside SLAC. Users would benefit from the state-of-the-art operations, maintenance, accelerator control, and beam diagnostics at SLAC and from the unique 300 MeV beam would be an essential for some of the experiments. However, this program and facility concept have been developed by a predominantly in-house SLAC faculty committee. At this point in time they are concrete enough to initiate discussions with the user community and yet preliminary enough that user input would be of significant value. We will be having a workshop in February, 2000 to get that input to develop the experimental program and facility.

An issue of particular interest is the mode of user participation in construction, operation, and in approval and scheduling of experiments. The committee thought that the PRT (Participating Research Team) approach would be a natural one for bringing user involvement. This approach is common at all of the synchrotron light sources. Users raise money for and develop parts of a facility in return for some guaranteed access without further review by a scientific program committee. A fraction of the time is available for proposals from the general user community, and recommendations for allocation of that time is determined by a program committee appointed by and reporting to the Director. A similar committee, perhaps the same committee, would evaluate proposals for development of the facility, i.e. for evaluating and recommending approval of the "PRT's".

The February workshop will be an opportunity for comments on this and other possible modes of operation.