The ORION Workshop

ORION is a facility for advanced accelerator research based on the Next Linear Collider Test Accelerator that is being considered as a future initiative at SLAC. A workshop about the ORION facility and scientific program was held on February 23 - 25, 2000. This is a report about that workshop.

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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."[1]

A SLAC user facility for advanced accelerator research could have this ideal combination and is being considered as part of the SLAC program. A faculty committee met during the summer of 1999 to study the possibilities. They looked at a number of accelerators and locations at SLAC, and determined that the NLCTA (NLC Test Accelerator) offered a good opportunity for a user facility with a wide-ranging scientific program that had the promise of significant advances. Appendix C is a description of the facility, which came to be called ORION.

That description is based on the committee report, and it was a starting point for the workshop. It has the ORION concept, facility configuration, and a possible experimental program. The February 2000 workshop was the next step in the development. Workshop goals were to get input from the potential user community to develop the experimental program and facility and to gauge the level of interest in the facility.

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[1] From the report of the SLAC faculty committee on an advanced accelerator research facility at SLAC (Appendix C).

ORION WORKSHOP ORGANIZATION

Chairs: Chan Joshi (UCLA) and Bob Siemann

Working Group	*Group Leader*	*Scientific Secretary*
High Gradient RF and RF Power Production	Hans Braun (CERN)	Dave Pritzkau
Plasma Acceleration	Tom Katsouleas (USC)	Andy Geraci
Laser Driven Accelerators and Structures	Ilan Ben-Zvi (BNL)	Chris Barnes
Particle and Radiation Sources	Jamie Rosenzweig (UCLA)	Ben Cowan

Program Coordination: Dennis Palmer ***Administrative Support:*** Angie Seymour

Those goals relate directly to two factors necessary to realize the promise that ORION offers. One factor is a commitment from SLAC to design, build, and operate the facility, and the other is the involvement of a user community working at ORION as a substantial component of their research.

The workshop agenda is in Appendix A. There were four working groups concentrating on different areas of accelerator research. Group memberships and workshop attendance are given in Appendix B. Most of the time was spent in working group discussions that led to reports in the closing session. This summary is devoted to the experiments discussed, the implications for the facility, and the working group conclusions.

WORKING GROUP I: HIGH GRADIENT RF AND RF POWER PRODUCTION

There is agreement that future RF driven linear accelerators will have high frequencies and high gradients, but there are open questions that have direct and important impact. These include the technology routes for high gradient acceleration and understanding the limits on accelerating gradient and the scaling of those limits with frequency, RF pulse length, and accelerator structure length. With respect to the latter, our knowledge of phenomena that limit accelerator gradients come from a relatively small number of experiments performed in the frequency range of 3 – 30 GHz, and in single-cell, standing wave, and traveling wave cavities. These different conditions make it difficult to compare experiments and develop an understanding that has predictive power.

Single-Cell Experiments - The recent 30 GHz, single-cell experiment at CLIC, reported by Hans Braun, serves as a model for a set of single-cell experiments studying the scaling of RF breakdown with frequency. The experiments would rely on a long-pulse beam bunched at 11.4 GHz. The harmonic content excites cavities at multiples of 11.4 GHz in the range f_{RF} = 23 – 103 GHz. The surface field depends on beam current as

$$E_{surf}(GV/m) = 0.43 I_{beam}(A)\sqrt{\frac{f_{RF}}{100\,GHz}}\,.$$

With a beam current, I_{beam} ~ 2 A, one could reach the breakdown levels at lower frequencies known from 11.4 and 30 GHz experiments. Higher beam current, I_{beam} ~ 3 A, would allow extending the experiments to higher frequencies. The invariant emittance of the long-pulse beam bunched at the fundamental frequency is ~ 100 mm-mrad. A beam with that emittance and E_{beam} = 70 MeV would pass through the aperture of cavities up to 46 GHz. Higher

NLCTA Performance for Long-Pulse Beams

	E_{beam}	I_{beam}
Present Injector Performance	60 MeV	1.6 A
Near Future Injector Performance	60 MeV	2 A
Adding a Second Klystron to the Injector	70 MeV	3 A
Present Performance at End of Linac	300 MeV	0.6 A
Future Performance at End of Linac	300 MeV	2 A
Injector with a Second Klystron & Two Short (Injector Style) Disk-Loaded Waveguides	140 MeV	3 A

frequencies require $E_{beam} \geq 140$ MeV. A bunch length $\sigma_z \leq 150$ μm is needed for efficient power production up to 103 GHz.

The present and anticipated, near future NLCTA beam parameters reported by Dian Yeremian are in the table above. A bunch length of $\sigma_z \leq 150$ μm could be achieved by a factor of two compression in the chicane. This has to be checked. The conclusion is that the performance expected in the near future will allow a start of an experimental program studying RF breakdown in single-cell cavities.

Travelling Wave Structures With Recirculation **–** Gradients achievable in multicell structures are lower than those obtained in single cells for reasons that are not fully understood. These multicell limits are the “engineering” values that are needed for linear accelerator design. In an experiment performed by Marc Hill, over 150 kW of W-band power was extracted from the COMPosite ACCelerator, a structure constructed of ceramic brazed on copper, driven by the NLCTA beam. Microwave energy was recirculated to reach this power level. Experiments similar to this could be performed with traveling wave structures at different frequencies. Beam parameters for this type of experiment are:

1. $I_{beam} = 2$ A is likely to be sufficient to reach breakdown limits.
2. $E_{beam} \geq 140$ MeV is needed because of the total deceleration that the beam experiences and the constraint of fitting through a small aperture at high frequencies.
3. $\sigma_z \leq 150$ μm is needed for efficient power production up to highest frequencies

Dielectric Structures **–** Dielectric structures are interesting at high frequencies because they avoid the problem of machining small features. Wei Gai reported interesting results and possibilities with a dielectric lined waveguide. There is no evidence of charging in experiments performed at ANL, and there have been no observations of breakdown for gradients up to 14 MV/m at 21 GHz. (This was the limit due to the drive beam of the ANL facility.) Performance limits of dielectric structures could be tested in experiments similar to those discussed above. Dielectric structures with R/Q ~ 100 Ω/m also offer interesting possibilities for power extraction in a two-beam accelerator. In addition, they could be the power source for either a second generation RF breakdown experiment that avoids having the beam pass through the cavity or for other structures such as a W-band RF gun. The power that could be generated is roughly

$$P_{out}(MW) = I_{beam}^{2} \frac{f_{RF}}{100\,GHz},$$

where I_{beam} is in Amps.

High power, high frequency klystrons and gyroklystrons are being developed. Wesley Lawson reported on a 10 MW, W-band gyroklystron, and Richard Temkin gave a presentation about a 17 GHz, 25 MW klystron. An advantage that ORION offers as a power source is coverage of the 23 - 103 GHz range in a single installation.

WORKING GROUP II: PLASMA ACCELERATION

The plasma working group looked at ten possible new experiments in the areas of plasma acceleration and focusing, beam physics, and radiation production. These experiments are described briefly and parameters are summarized in a table near the end of this section.

The conclusion of the working group was that ORION has a potential for important new plasma-beam physics experiments. The variety and richness of the experimental program below demonstrate this. Most of these experiments require a beam with charge Q = 1 nC and bunch length σ_z = 1 psec. A beam with those properties would allow the start of most of this program.

Multi-Bunch Plasma Wakefield Acceleration – The two-bunch configuration with a driving bunch and separate trailing bunch was simulated for ORION parameters and 1 m long plasma with a density $n_0 = 5\times10^{14}$ cm^{-3}. For a drive bunch with Q = 1 nC and σ_z = 1 psec the 300 MeV ORION beam could be accelerated to 500 MeV. The trailing bunch should have Q ~ 0.2 nC and a variable bunch length in the 0.2 to 0.5 psec range for systematic studies.

High Transformer Ratio Plasma Wakefield Acceleration – This experiment would be a study of the bunch shape dependence of the transformer ratio. The critical experimental issue is shaping the bunch, and possible techniques are use of the magnetic chicane by itself or in combination with an energy chirp on the bunch.

Electron Hose Instability – This instability is a potential serious limit to plasma accelerators. It has been the subject of extensive simulations and discussions, particularly in the context of SLAC experiment E-157 where the effects seem to be marginal. ORION offers the possibility of a systematic study of this instability including its onset and saturation.

High De-magnification Plasma Lens – Aberrations in plasma lenses could be measured with a high demagnification, m > 5. With a 300 MeV, high quality beam and a 0.15 m long plasma with plasma density $n_0 = 1\times10^{12}$ cm^{-3} one could de-magnify a 400 μm spot to 4 μm. Single-shot, OTR based diagnostics with ~ 5 μm resolution are essential for this experiment.

Energy Spread Compensator – The correlated energy spread in the beam from a large linac can be compensated by a plasma wakefield accelerator that transfers energy from the head to the tail. This principle could be demonstrated at ORION by reducing the energy spread of a bunch from ~10% to ~1%.

Self-Modulated Plasma Wakefield Acceleration – When the plasma skin depth becomes much shorter than the bunch length, the bunch can exhibit a two-stream instability that modulates it at the plasma frequency. The modulated beam can then act as a multi-bunch plasma wakefield driver giving very large wakefield amplitudes. This mechanism is of interest because of its potential for making incredibly high acceleration gradients and because of its simplicity – it may not even be necessary to pre-ionize because impact ionization of a dense gas may be sufficient to form the plasma. The degree to which the instability can be precipitated and controlled are completely unknown. No experimental data exist in this regime of beam-plasma physics.

Laser Steering and Slicing of Electron Beams – It has been observed in E-157 that during alignment procedures the electron beam tends to follow the laser beam used to create the plasma due to a type of off-axis plasma lensing. This simple demonstration intimates the

Plasma Acceleration Experiments

Experiment	*Energy* (MeV)	*Charge* (nC)	σ_z (psec)	σ_r (μ)	ε (mm-mrad)	$\Delta\gamma/\gamma$	L_p (m)	n_o (cm^{-3})	*Output*	*Issues*
Two-Bunch PWFA	300	1, 0.2	1 .2-.5	70μ	70	0.1	1m	5×10^{14}	500 MeV beam	Phasing 2 Bunch lengths
Bunch Shaping	300								Half-Gaussian	Isochronous bend
High Trans. Ratio Experiment		(4)	(4)				(.5m)	(1×10^{16})	(1.5 GeV)	
Electron Hose Instability	300	1	1	50	10	0.1	1m	1×10^{15}	Onset/saturation Blowup of beam	Simulations pending
Hi De-magnification Lens	300	1	1	400	3.5	0.01	0.15	1×10^{12}	4 μ spot	Aberrations/ diagnostics
Energy Compensation	300	1	1 ps + tail	50-100	5	0.1	0.3m	2×10^{14}	1% energy spread	200 fs streak camera
SMPWA								1×10^{21} gas	Acceleration?	Impact ionization Simulations!
E-Beam Slicing	50	1	1	20-40	3.5	0.1	0.15	4×10^{17}	Energy mod. 1MeV	TiSa laser Hi Vosc
E-Beam Steering	50 or 300	1	1	50-100	10	0.1	0.3	1×10^{14}	Deflected e-beam	--
Laser Guiding	50 or 300	1 kA	0.5-1	20	60	N/a	0.5m	1×10^{15}	Laser Transported 100 LR	Split photo-Cathode laser
Ion Channel Laser @ 50 MeV	50	1 nC/ps	>0.05	<60	5	0.05	0.2m	1.4×10^{15}	630 nm, 10^{10} gain $.02\text{-}10^{6}$ γ/e	Hosing? Models
Ion Channel Laser @ 300 MeV	300	1 nC/ps	>0.05	60	4	0.03	1.5m	4×10^{14}	80 nm	Gain?
Coh. Plasma Cherenkov Radiation	50 or 300	1 or 0.25	1 0.5	200	100	0.1	1m	4×10^{14} to 1×10^{16}	200 Ghz+ 1-10kW	Sharp Boundary/ B-field diffraction
Positrons									Many possibilities	

Notes: σ_z = bunch length; σ_r = spot size (assumed round); ε = normalized emittance; $\Delta\gamma/\gamma$ = fractional energy spread; L_p = plasma length; n_0 = plasma density possibility of powerful new tools for manipulating beams, including magnetless kickers and beam slicers that could turn on and off on unprecedented time scales. The basic physics of these mechanisms could be systematically explored at the ORION facility.

Electron Beam Guiding of Lasers **–** This is a potential mechanism for extending laser wakefield accelerators to the meter length scale. An electron beam creates a plasma channel that guides a laser roughly 100 times the Rayleigh length. A test of electron beam guiding over ~ 0.l5 m could be performed at ORION with a 1 kA peak current beam.

Ion Channel Laser **–** The wiggler magnet of a single-pass FEL is replaced with a plasma cell. An ion focusing channel is formed, and the betatron oscillations in the channel lead to synchrotron radiation, and potentially, to Self-Amplified Spontaneous Emission. A demonstration could be performed in the visible spectrum with a 50 MeV beam. Ultraviolet radiation at 80 nm could be demonstrated with the 300 MeV beam.

Coherent Plasma Cherenkov Radiation **–** A magnetized plasma can be used to couple out microwaves produced in a plasma wakefield. Multi-kW sources in the 100 GHz to THz frequency ranges would be possible at ORION.

Beam Diagnostics **–** Many of these experiments require good beam diagnostics. Two essential ones are a 200 fsec resolution streak camera and high spatial resolution ($\leq$ 5 μm), single-shot OTR diagnostics.

Plasma Simulations **–** Simulations are an essential partner to this experimental program. The implications of the ORION experiments for plasma simulations are

- Parallel two- and three- dimensional PIC simulations with a moving window are fundamental.
- A quasi-static PIC model would be highly beneficial.
- Electron-impact ionization needed for the Self-Modulated Plasma Wakefield case.
- Combination of PIC and modified FEL algorithms needed for high-fidelity simulations of the Ion Channel Laser.
- Good interface between PIC codes and conventional beam optics codes will be required.

WORKING GROUP III: LASER DRIVEN ACCELERATORS AND STRUCTURES

The objective of this working group was to provide a list of ORION attributes and specifications based on past experience and also by looking at some specific experiments.

ICA/STELLA Experience **–** Wayne Kimura has been performing laser acceleration experiments for over twenty years. Two of these experiments are the Inverse Cherenkov Accelerator (ICA) and Staged Electron Accelerator Experiment (STELLA) at the Accelerator Test Facility at Brookhaven. The ICA experiment, which used a 30 MW Nd:YAG laser (1.06 μm) and a 102 MeV electron beam, demonstrated interaction between the laser and electron beams via the inverse Cherenkov effect. The STELLA experiment is ongoing and is based on a ~ 1 GW CO_2 (10.6 μm) laser and a 40 MeV electron beam. The objective is to bunch a beam at optical wavelength with an inverse FEL and then accelerate this beam using the inverse Cherenkov effect.

Lessons from this experience are:

- The quality of data is directly related to the quality of the electron and laser beams. Measurement and control of beam quality and shot-to-shot stability are important.
- It is critical to have a complete set of good diagnostics. Sensitivity, resolution, linearity, dynamic range and whether or not a diagnostic is real-time or requires special set-up/running conditions can all be important. Poor shot-to-shot reproducibility requires more

real-time diagnostics to combine data. Electron beam properties to be measured can include energy, emittance, charge, energy spread, and pulse length. Laser properties are pulse energy, pulse length and shape, beam quality, and focal dimensions and position. Additional diagnostics are needed to measure temporal and spatial overlap of the beams.

- Experiments require extensive preparation time without an electron beam, but sometimes requiring the laser beam. The ideal facility would be one where there can be access for set-up and preparation while another experiment is using the electron beam. Examples for ORION would be access to either the Low Energy Hall or the High Energy Hall while the other has beam. In addition, a laser protection system that maximized access while others are using the laser would be valuable. Run time is a premium and investments in shielding and interlock systems that increase run time will pay off directly in progress and experimental results.

***LEAP* –** (Presented by Tomas Plettner) The LEAP experiment is the first of four experiments examined in detail by the working group to consider attributes that ORION should have.

LEAP is an experimental study of laser acceleration that has the theme of working at short wavelengths where there are strong economic forces leading to rapidly improving laser performance. The first experiment, which is in progress at the Hansen Experimental Physics Lab on the Stanford campus, is a single-cell dielectric structure driven by a ~ 850 nm Ti:Sapphire laser. It is a proof-of-principle experiment aimed at measuring laser acceleration in a simple structure. Future plans include multiple cells to demonstrate staging and bunching and the design and testing of structures that can be fabricated lithographically.

***TOP* –** (Presented by Yen-Chieh Huang) The experiment is designed to study the fundamentals of the laser-electron beam interaction. It is a 5 cm long, 1.75 mm diameter laser resonator with electron transmitting holes designed for a 10 μm laser to ease cavity fabrication tolerances. An accelerating gradient of ~ 10 MeV/m is possible.

***INVERTED MEDIUM* –** (Presented by Levi Schächter) Energy is stored in an active medium such as Nd:Yag or Ti:Sapphire by optical pumping. A low charge beam pulse enters a hole at the center of the medium, and the wakefield from this trigger bunch is amplified by its interaction with the active medium. The wakefield grows exponentially and produces a high-gradient accelerating field for a trailing bunch.

***AGLA* –** (Presented by Ming Xie) Laser accelerators are characterized by a phase slip between the laser and electron beams that eventually turns acceleration into deceleration. The principle of Alternating Gradient Acceleration is to have alternating accelerating and decelerating sections but to limit the length and/or energy loss in the decelerating sections to have net energy gain.

One example of this general principle was considered. A capillary open waveguide with inner radius $R = 300$ μm and a $\lambda = 1$ μm laser. A magnetic field produces a wiggle in the orbit that makes the decelerating length ~ 30% of the accelerating length. An effective gradient of 97 MeV/m is achieved with a 1 TW laser.

***SUMMARY TABLE* –** A summary table of parameters and other requirements was developed for these four experiments.

Laser Acceleration Experiments

QUANTITY/ EXPT	LEAP	TOP	INVERTED MEDIUM	AGLA
Electron Beam				
Energy	> 30 MeV, < 60 MeV	50 MeV	300 MeV	300 MeV best
Pulse length	~ 1 psec	Any OK	3 psec	Covered by columns
Particles	10^6 to 10^8	10^7	$<10^9$	on left
Energy Spread	0.1% FWHM	0.10%	Same	
Normalized Emittance	1 μm	1 μm		
Charge Stability	10% FWHM	10% FWHM		
Timing Stability	< 1 psec	1 psec		
Energy Stability	< 1/2 expected effect = .5*100 keV	0.10%		
Pointing Stability	3 μm at expt.	10 μm		
Electron Beam Diagnostics				
Spectrometer	10 % acceptance, 0.01% resolution	0.01%	100 MeV range around 300 MeV, 0.03% resolution	
Charge	needed	0.1 pC/pulse	Needs to see a low charge seed bunch, 10^4-10^6 particles	
Position	needed	<10 μm		
Emittance	needed	0.1 μm		
Pulse Length	needed	needed		
Laser				
Energy	1 mJ/stage	.1 - 1 GW		1 TW
Pulse Length	1 - 10 psec	10 nsec		10's-100 fsec OK
Wavelength	1 μm	10 μm		1 micron
Mode Quality	$m^2 < 2$	TM_{10}		
Energy Stability	5% FWHM	5% FWHM		
Timing Stability	(Laser Pulse Length)/3	100 psec		
Pointing Stability at Expt	3 micron	10 micron		
QUANTITY/ EXPT	**LEAP**	**TOP**	**INVERTED MEDIUM**	**AGLA**
Laser Diagnostics				
Energy	Shot-to-Shot at Experiment	Power meter	0.5 - 1 μm detection	
Position	Monitor Position in Transport Line			
Pulse Length	Streak Camera	Optical Microbunching Diagnostic	Streak Camera	
Other				
Space on Beam Line	Matching 2m, experiment 2m, downstream 2 × 2 m			
Space Around Beam Line	1.5 × 2.5 m table			
Control Room Space	Light analysis room nearby with two optical tables			
Access Time	20% of run time			
Run Time	48 hrs/week × 12 weeks for one experimental study	10% as much		
Safety	Radiation and laser safety compatible with access to one experimental area while lasers and beams are present in another area			
Special Requirements			Two bunch e with variable (short) delay	

WORKING GROUP IV: PARTICLE AND RADIATION SOURCES

X-band or S-band RF Gun - ORION requires two different electron sources. One is the present injector that produces a several hundred-nsec long pulse bunched at X-band. It is needed for the RF related experiments discussed by Working Group I. Most other experiments need a single bunch with the characteristics of the beam from an RF photocathode gun. Such a gun is central to the ORION experimental program and needs to be developed. There is abundant X-band RF power at the NLCTA, and designing and developing an X-band RF gun is an attractive research topic. However, pursuing X-band gun R&D may be in conflict with providing beam to other experiments.

There is an alternative that should be given serious consideration. It is building another BNL/SLAC/UCLA 1.6-cell S-band RF gun (parameters in the table below) and following that gun with a SLAC S-band section to accelerate the beam to roughly 35 MeV. This would be in the straight-ahead line to avoid emittance dilution of the high brightness beam, and the present long-pulse gun together with the first X-band section would be moved off-axis. The beams would be merged at 35 MeV. A major disadvantage is that it requires S-band as well as X-band power.

Chicane - The original ORION description (Appendix C) assumed that the chicane at the end of the injector would not be compatible with high brightness beams because of coherent synchrotron radiation and that the chicane would have to be bypassed under those conditions. The chicane bends are sufficiently gentle that this does not seem to be necessary, and the chicane fulfills the need of having a compressor for bunch shortening. Eliminating the chicane bypass is a significant simplification.

RF Gun Development **–** ORION would have the resources for an active program in electron source development. These include the photocathode drive laser and RF power at S-band (if an S-band injector is installed), X-band, and at X-band harmonics using structures driven by the NLCTA beam. The experimental program could include

- An integrated, hybrid X-band photoinjector. The gun itself would be in a two-cell standing wave cavity followed by a seven-cell traveling wave section that is part of the same RF structure.
- An X-band Plane Wave Transformer photoinjector.
- Development of an RF gun that produces polarized electrons.
- Production of an NLC-like pulse train with up to 200 bunches separated by 1.4 to 2.8 nsec.
- A W-band photoinjector that uses ballistic compression for synchronization with the RF.

ORION should include a separate shielded area for this type of R&D. This area could be included in the facility at a modest cost and enhance the ORION capabilities and increase the experimental program.

S-Band RF Gun and Laser System

1.6 Cell RF Gun		Laser System	
Charge	1 nC	**Laser System**	Ti:Sapphire
Energy	4.5 MeV	**UV Energy**	500 μJ
Peak Current	100A	**Pulse Structure**	Single
RMS Energy Spread	0.1%	**Pulse Shape**	Hard Edge
Bunch Length	10 psec	**Pulse Length**	10 psec
Normalized Emittance	0.75×10^{-6} m	**Cathode Spot Diameter**	1 mm
Cathode	CU_{100}		
Cathode Quantum Efficiency	6×10^{-5}		

Photocathode Drive Laser – Laser Room 1 (Figure 2, Appendix C), which is intended for the drive laser, has adequate area. It should be a class 10000 clean room. The laser for a single bunch system can be an off-the-shelf Ti:Sapphire based system. Parameters are in the table above.

There are several enhancements that are outside the original ORION scope, but could be considered. They are the development of a laser system to generate the NLC micro-pulse train and a CsTe cathode. Both would add costs; the estimate for the former is $1 M.

Radiation Source Physics – There are two general classes of radiation source experiments possible at ORION. One is related to SASE (Self-Amplified Spontaneous Emission) and FEL's (Free Electron Lasers), and the other related to Compton scattering sources.

SASE and FEL's – Demonstration of SASE in the visible and ultraviolet is a critical step in the development of X-ray FEL's, and experiments at Argonne, Brookhaven, and DESY are devoted to this. There are exciting results from these experiments already, and the present questions about SASE start-up and saturation will be answered long before ORION is available. Therefore, the viability of a SASE/FEL program at ORION depends on whether new issues arise, and the role that a soft X-ray FEL could have in SLAC's plans to develop the Linear Coherent Light Source.

There is also the possibility of a user facility for soft X-ray physics. This would have to be coordinated with SSRL, and strong motivation is needed since the required 6 – 8 m long undulator would cost ~ $1M.

Compton Scattering – Multi-MeV gamma rays can be produced by Compton scattering of photons from a 10 TW class laser (see parameters below). These gamma rays could be used for the study of photonuclear physics, production of polarized positrons, and production of polarized neutrons. For example, circularly polarized γ's at E_γ = 2 and 5 MeV incident on B^9 and C^{13} are predicted to produce 50 and 100% polarized, quasi-monochromatic neutrons, respectively.

The laser would find use in laser acceleration and plasma experiments also, and the laser and ORION beam offer the possibility of research in fundamental physics of interactions between relativistic electron and intense laser beams.

Laser Room 2 would have to be 50 % larger than the current plan. Experimental space is at a premium, and having a larger High Energy Hall would allow space for a wide variety of experiments.

Incident Photon Angles to Produce Gamma Rays of Different Energies (E_{e-} = 350 MeV)

$\lambda \backslash E_\gamma$	0.2 MeV	0.8 MeV	2 MeV (Be^9)	5 MeV (C^{13})	E_γ^{max}
0.25 μm	16.9°	34.1°	55.5°	95.3°	9.06 MeV
1.0 μm	34.1°	71.9°	136.8°		2.31 MeV
2.5 μm	55.4°	136.3°			0.93
10.6 μm	145.5°				0.22

λ = incident photon wavelength, E_γ = scattered photon energy

SUMMARY

The workshop goals were *i)* to get input from the potential user community to develop the experimental program and facility, and *ii)* to gauge the level of interest in ORION.

The previous four sections discuss the experimental program. It is wide-ranging with significant experiments in many areas of accelerator research. It includes experiments devoted to understanding the limitations of RF driven accelerators, new experiments in many aspects of beam-plasma interactions, advances in laser driven accelerators, and development of new electron beam sources.

There were several specific recommendations about the ORION facility.

1. The need for two injectors was confirmed. One is the present injector that is capable of making roughly 100 nsec long beam pulses bunched at X-band. The other would be a high brightness, RF photoinjector making single beam pulses with 1 nC charge and 1 psec rms bunch length. It was recommended that this gun be an S-band gun.
2. There is no need to build a chicane bypass.
3. Consideration should be given to building a separate shielded area for gun development.
4. A complete set of good laser and electron beam diagnostics is critical. Sensitivity, resolution, linearity, dynamic range and whether a diagnostic is real-time or requires special set-up/running conditions can all be important.
5. Careful consideration should be given to shielding and interlock systems that would allow access for preparation and set-up while other experiments are using electron or laser beams. This will give a significant increase in effective running time for experiments.
6. The experimental hall and laser room sizes should be reviewed thoroughly.

There is significant interest in ORION. The workshop was well attended, and it is clear that there is an exciting experimental program with many opportunities. Anchored by SLAC’s expertise in operating user facilities and with an active, engaged user community, ORION promises to become the focus of a research program that rapidly advances accelerator science.

APPENDIX A – WORKSHOP AGENDA

Wednesday, February 23, 2000 to Friday, February 25, 2000

The ORION Workshop

	Weds	*Thurs*	*Friday*
8:30	Coffee	Coffee	Coffee
9:00	Opening Session Details Below	Working Group Meetings	Working Group Meetings
10:30		Coffee Break	Coffee Break
11:00		Working Group Meetings	Working Group Meetings
12:30	Lunch	Lunch	Lunch
13:30	Working Group Meetings	Working Group Meetings	Closing Session Details Below
15:00	Coffee Break	Coffee Break	
15:30	Working Group Meetings	Working Group Meetings	
17:00	Workshop Social Event	NLCTA Tour	

Opening Session

	Presentation
9:00 – 9:15	Director's Greeting – Jonathan Dorfan
9:15 – 9:30	Workshop Overview – Bob Siemann
9:30 – 10:00	The NLCTA – Chris Adolphsen
10:00 – 10:20	A Description of the ORION Facility – Dennis Palmer
10:20 – 10:35	The Promise of the ORION Facility – Bob Siemann
10:35 – 11:00	COFFEE BREAK
	Working Group Introductions
11:00 – 11:20	The High Gradient RF and RF Power Production – Hans Braun
11:20 – 11:40	Plasma Acceleration – Tom Katsouleas
11:40 – 12:00	Laser Driven Accelerators and Structures – Ilan Ben-Zvi
12:00 – 12:20	Particle and Radiation Sources – Jamie Rosenzweig

Closing Session

	Presentation
1:30 – 2:00	Plasma Accelerators – Tom Katsouleas
2:00 – 2:30	High Gradient RF and RF Power Production – Hans Braun
2:30 – 3:00	Laser Driven Accelerators and Structures – Ilan Ben-Zvi
3:00 – 3:30	Particle and Radiation Sources – Jamie Rosenzweig
3:30 – 3:40	Workshop Closeout – Bob Siemann

APPENDIX B – WORKSHOP PARTICIPANTS

Working Group I: High Gradient RF and RF Power Production	
Hans H. Braun (Group Leader)	PS - Division, CERN
David Pritzkau (Scientific Secretary)	SLAC
Chris Adolphsen	SLAC
Karl Bane	SLAC
Alex Chao	SLAC
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APPENDIX C - 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.

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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 experimental area at 50 MeV that would rely on beam from the injector.
- 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.

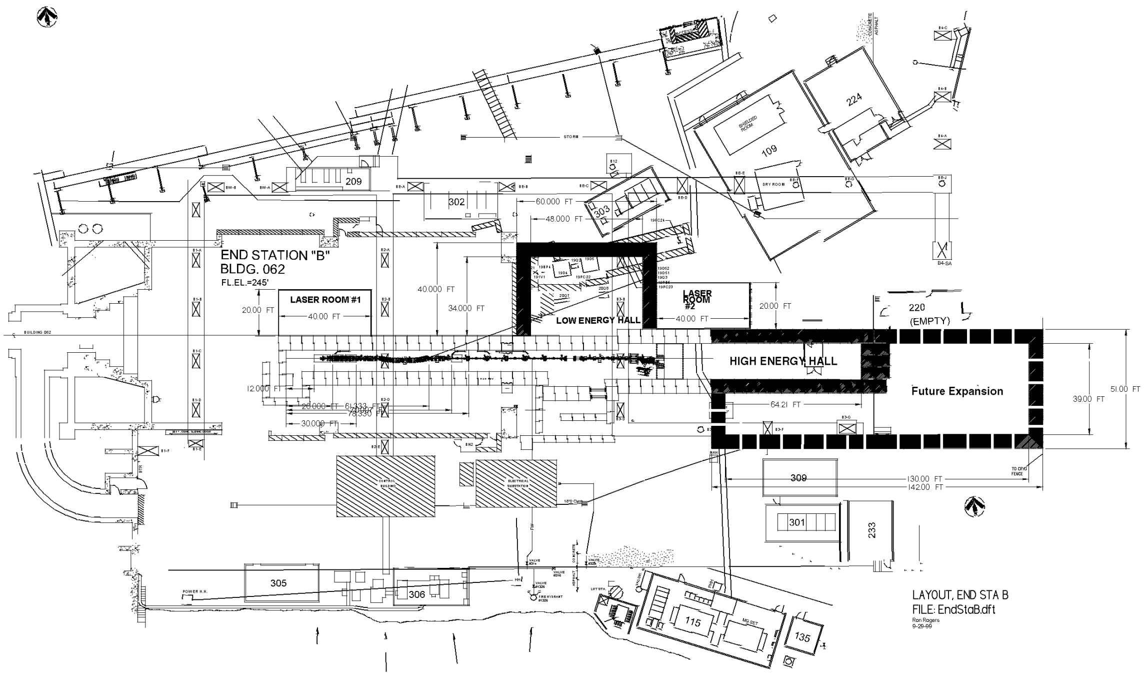

Figure 1: The NLCTA with the Accelerator Research Facility added. The facility consists of a Low Energy Hall, a High Energy Hall, and two laser rooms. The plan would be to initially extend the NLCTA tunnel to make space available for experiments and leave the full-sized High Energy Hall as a later option.

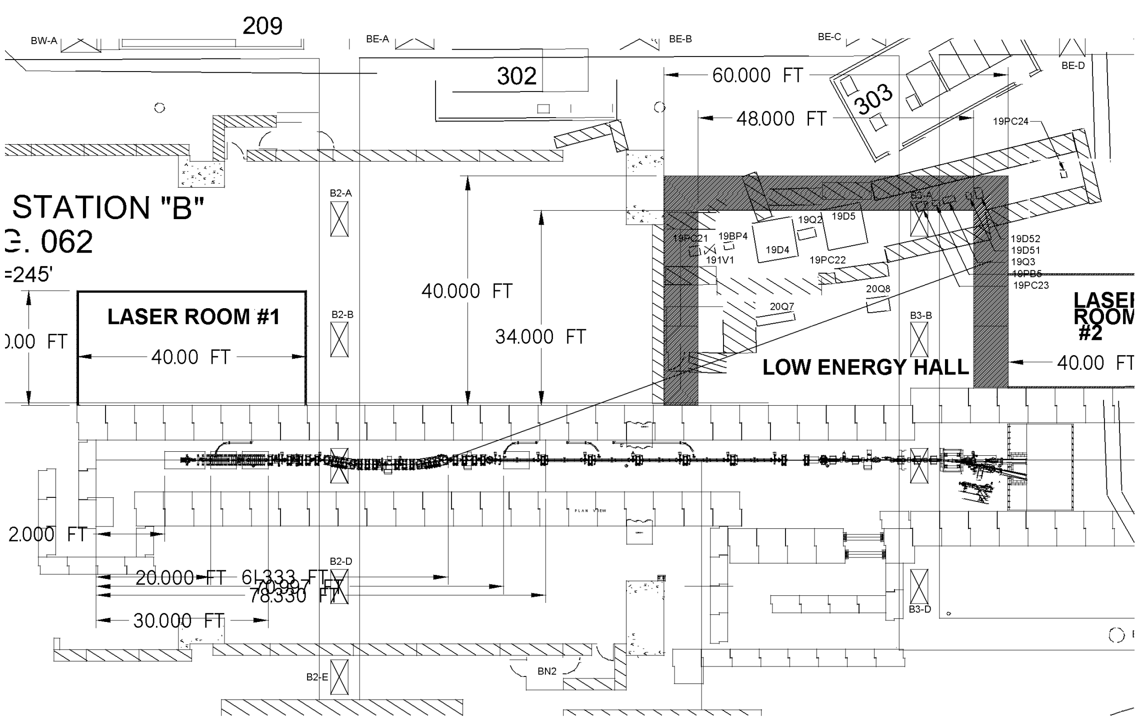

Figure 2: An expanded view showing the NLCTA and the extraction point for the Low Energy Hall.

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.

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.