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# An Accelerator Research Facility At SLAC

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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.

This is an opportunity for SLAC. An advanced accelerator research facility will serve as a user facility to attract scientists from universities and national laboratories with a passion for advanced accelerator research. A facility to serve this need would secure a place for SLAC at the center of research and development of advanced accelerators. It was first presented at the SLAC Faculty Retreat in April, 1999. The concept is an accelerator research facility where the needed resources (electron beams, lasers, beam diagnostics, utilities, space, etc.) are readily available and where scientists from universities and other national laboratories are welcome and can participate in a meaningful way. An analogy is End Station A in the late 60's and early 70's where a major facility was developed; there was active engagement of the user community, and there was a tremendous advancement in science because each experiment required only modest changes to existing equipment.

Jonathan Dorfan established this committee with the following charge:

SLAC is considering the development of a facility for advanced accelerator research. The Laboratory would like to have an evaluation of such a facility including the following points:

1. A possible experimental program and the technical requirements for a facility to carry out that program including properties of the accelerator, associated lasers, and beam and laser diagnostics. An implementation plan(s) and the associated costs are needed.
2. Ways to involve users in the development and utilization of such a facility.
3. The most economical facility could be based on the NLCTA. What would be the technical and scheduling issues associated with an NLCTA-based facility?

This report addresses that charge with a description of an accelerator research facility based on the NLCTA. It includes an experimental program, a model for user participation, a description of the facility scope, and a cost estimate.

## *A Facility Based On The NLCTA*

The NLC Test Accelerator, the NLCTA, could serve admirably as the centerpiece of a unique, world-class facility for advanced accelerator research. No other possibility at SLAC offers what it does because of limited space and/or energy or because of the cost to duplicate the NLCTA infrastructure, accelerator, and performance.

The NLCTA consists of an 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 $\sim 10^8$ 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.
- An extension of the NLCTA shielded area beyond the present dump for experiments at 300 MeV.

Details are presented following the discussions of the experimental program and user participation.

## *An Experimental Program*

A 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.

***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 ($1\text{-}2\times10^{-6}$ m), High peak current beam |
| Laser Acceleration | Single Bunch, 0.002 - 0.002 nC | 50 | Modest emittance ($\sim10^{-5}$ m), 1-2 psec pulse length, 0.10% energy spread |
| Coherent Synchrotron Radiation | Single Bunch, 1 nC | 300 | Low emittance ($1\text{-}2\times10^{-6}$ 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 | |

*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 low energy measurements are dominated by space charge effects. 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.

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 accelerator research facility. The first is demonstration in 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.

### *User Participation*

The experimental program above has the potential of significant interest from users outside SLAC. In addition to being of general interest, harmonic power generation and high frequency, high gradient tests are of particular importance to CERN physicists. The laser acceleration experiments would be a continuation of work with physicists from the Stanford campus, and different groups at UCLA have a history of interest in high brightness sources, emittance compensation, coherent synchrotron radiation, and plasma acceleration. Femtosecond x-ray production is an area of interest to physicists at UC Davis and LLNL.

These are particular examples, but the facility would have features that are attractive to the user community. These include:

*SLAC support:* SLAC has developed sophisticated, state-of-the-art operations, maintenance, accelerator control, and beam diagnostics capabilities. The hardware, software, protocols, and procedures are uniform across the High Energy Physics part of the lab. This allows rapid development of and good maintenance for the routine aspects of accelerator experiments. Users can count on a solid foundation for building their experiments, and they can concentrate on the new physics and technology they are studying.

SLAC experiment E-157 serves as an example. The FFTB with appropriate modifications was provided by the lab. All of the capabilities of SLC controls and beam diagnostics were available. Of particular importance were pulse-by-pulse current and orbit readout and the SLC timing system. The experimenters provided the plasma cell, ionization laser, and the OTR and Cerenkov diagnostics unique to the experiment. These diagnostics were easily coordinated with the SLC controls.

*High beam energy:* A 300 MeV beam would be unique and an essential feature for some of the experiments.

*West Coast location:* The US accelerator research community has a high concentration on the West Coast. SLAC's location is convenient for West Coast users from considerations of both time and travel costs.

Many of the experiments above are significant scientific opportunities. Some require apparatus and equipment developments that are natural for users to pursue for both the intrinsic interest in the particular development and for the experiments that would be possible upon completion of the apparatus. Examples include design and development of an X-band RF gun and the laser system for driving that gun and other laser driven devices.

The PRT (Participating Research Team) approach is the natural one for bringing user involvement in facility development. 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".

This is the appropriate mode for developing an advanced accelerator facility. While common for synchrotron light sources, it is a new mode for high energy physics. It gives users a vested interest in the facility and at the same time gives them some responsibility for raising money. While an appropriate allocation of time for PRT's vs general proposals needs wider discussion than in this committee, our suggestion is that 70% of the time be allocated for the PRT's and 30% for general proposals.

### *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 and a possible implementation plan.

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.

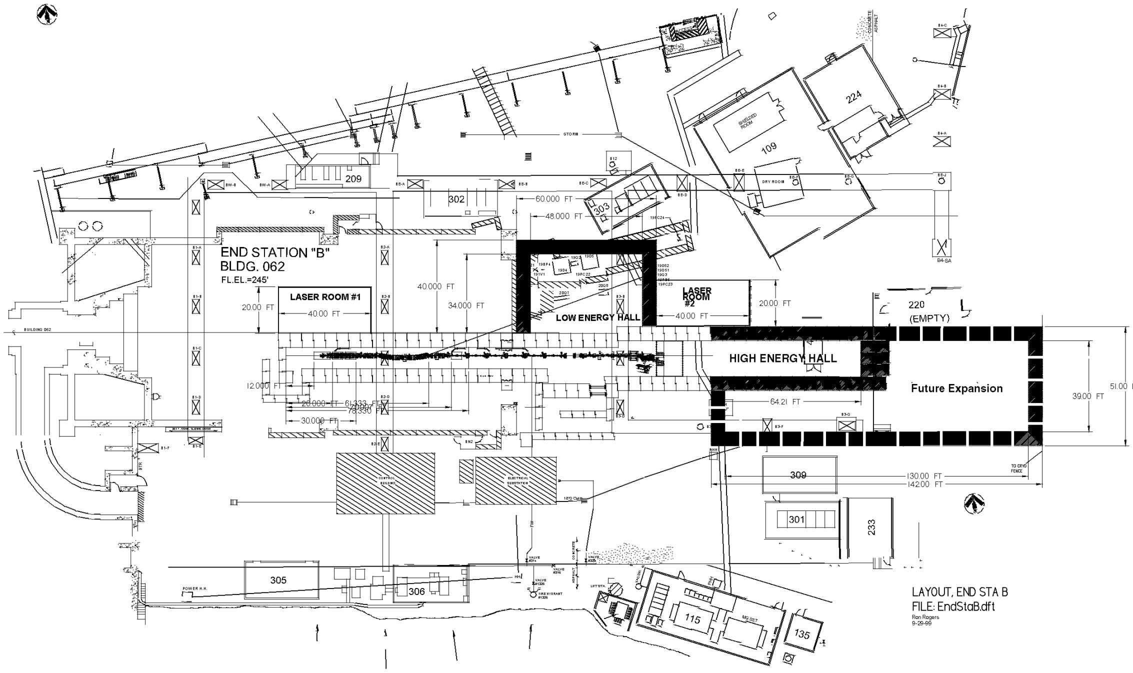


Figure 1: The NLCTA with the Accelerator Research Facility added. The facility consists of a Low Energy Hall, a High Energy Hall, and two laser rooms. The plan would be to initially extend the NLCTA tunnel to make space available for experiments and leave the full-sized High Energy Hall as a later option.

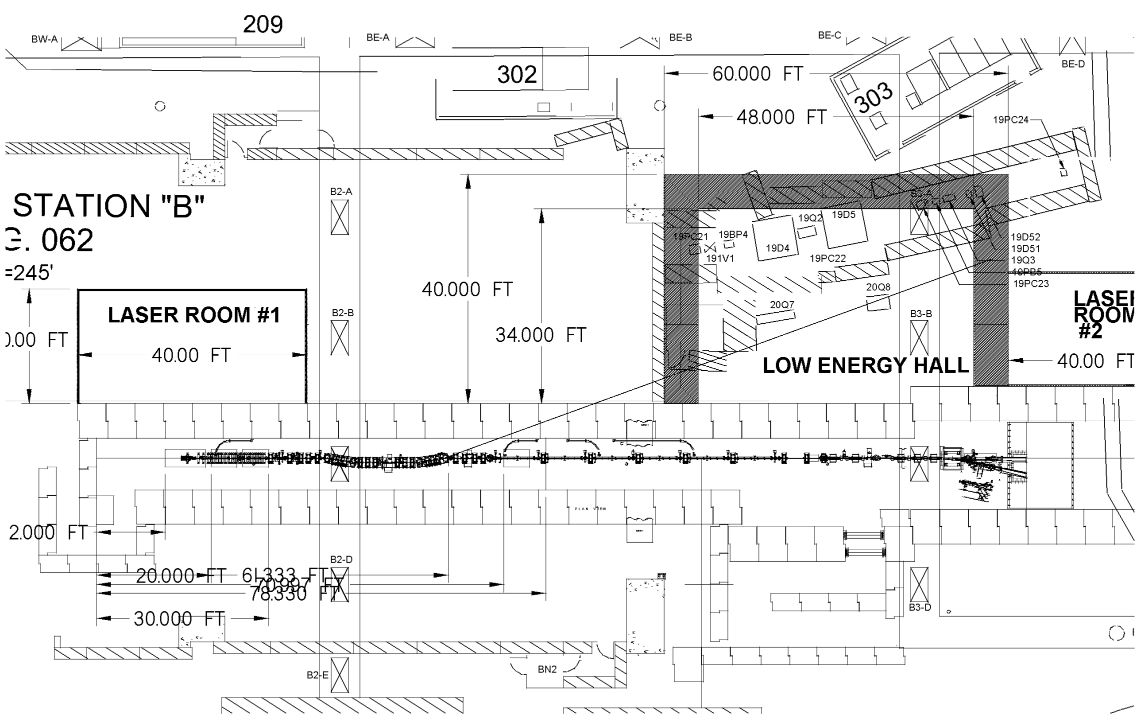


Figure 2: An expanded view showing the NLCTA and the extraction point for the Low Energy Hall.

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 ~$2\times10^{-6}$ 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.

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 cost estimate has been developed with the following 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 rough, preliminary cost estimated with these assumptions is $3.6 M. It is broken down and presented in Table 2. There are a number of possible ways to save money including a simplified beam profile monitor design, commercial, air-cooled quadrupoles rather than in-house, water cooled ones, a copper rather than stainless steel LCW system, and scrounging.

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.

### *Summary and Conclusions*

Establishing an accelerator research facility at SLAC is a significant opportunity for the Laboratory to use its resources to establish a center in an important area of science and to involve the user community. It would bring a new vitality to the advanced accelerator research that is so important for particle physics.

The NLCTA could serve admirably as the centerpiece of this facility. The cost to construct a facility based on the NLCTA is estimated to be $3.6M.

An possible experimental program using 50 and 300 MeV beams has been presented. It has breadth with a wide variety of forefront experiments, but leaves many other opportunities for the future.

An approach modeled after the Participating Research Teams common at synchrotron light sources would give users a vested interest in the facility and at the same time responsibility for raising money.

## *Table 2: Cost Estimate* **3,543**

| | | | |
|---|---|---|---|
| 1.1 Conventional Facilities | | 1,047 | |
| 1.1.1 | Low Energy Hall (LEH) | | *266* |
| 1.1.2 | High Energy Hall (HEH) | | *199* |
| 1.1.3 | AC Power | | *93* |
| 1.1.4 | WATER/AIR/FIRE | | *77* |
| 1.1.5 | Cable Plant | | *236* |
| 1.1.6 | Trailers | | *175* |
| 1.2 Source | | 743 | |
| 1.2.1 | X-Band RF Gun | | *45* |
| 1.2.2 | RF Waveguide System | | *108* |
| 1.2.3 | Emittance Compensation Solenoid | | *35* |
| 1.2.4 | Diagnostics Line | | *116* |
| 1.2.5 | Laser System | | *440* |
| 1.3 Vacuum | | 51 | |
| 1.3.1 | Vacuum System | | *51* |
| 1.4 Magnets | | 171 | |
| 1.4.1 | Quadrupoles | | *135* |
| 1.4.2 | Support Girders | | *36* |
| 1.5 Magnet Power Supplies | | 80 | |
| 1.5.1 | Quadrupoles | | *41* |
| 1.5.2 | Dipole Correctors | | *39* |
| 1.5.3 | Solenoid Magnet | | *4* |
| 1.6 Beam Devices | | 507 | |
| 1.6.1 | BPMs | | *127* |
| 1.6.2 | Profile Monitors | | *116* |
| 1.6.3 | Wire Scanners | | *106* |
| 1.6.4 | Toroids | | *35* |
| 1.6.5 | Faraday Cup | | *39* |
| 1.6.6 | Collimator | | *86* |
| 1.7 Protection Systems | | 254 | |
| 1.7.1 | Beam Containment Systems LEH | | *75* |
| 1.7.2 | Beam Containment Systems HEH | | *75* |
| 1.7.3 | Personnel Protection Systems LEH | | *35* |
| 1.7.4 | Personnel Protection Systems HEH | | *10* |
| 1.7.5 | Laser Safety System LASER #1 | | *25* |
| 1.7.6 | Laser Safety System LASER #2 | | *25* |
| 1.7.7 | Beam Stops (2 each) | | *10* |
| 1.8 Controls | | 128 | |
| 1.8.1 | System Engineering & Integration | | *27* |
| 1.8.2 | Vax/Multibus Interface | | *20* |
| 1.8.3 | Micro System | | *9* |
| 1.8.4 | Camac System | | *53* |
| 1.8.5 | Signal Processing | | *11* |
| 1.8.6 | Timing System | | *5* |
| 1.8.7 | Interlock Power & Trunking | | *4* |
| 1.9 Installation | | 111 | |
| 1.9.1 | Alignment Systems Installation | | *27* |
| 1.9.2 | Mechanical Systems Installation | | *9* |
| 1.9.3 | Vacuum Systems Installation | | *4* |
| 1.9.4 | RAD Shielding Installation | | *71* |
| 1.10 Management | | 450 | |
| 1.10.1 | Staff | | *400* |
| 1.10.2 | M&S | | *50* |