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REPORT DOCUMENTATION PAGE

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OMB No. 0704-0188

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1. AGENCY USE ONLY (Leave blank)		2. REPORT DATE 28 Mar 1990	3. REPORT TYPE AND DATES COVERED Final Report/1 Dec 88-30 Nov 89	
4. TITLE AND SUBTITLE (U) DURIP - INSTRUMENTATION FOR LASER SWITCHED POWER LINAC			5. FUNDING NUMBERS 61104D/3842/A6 SDI	
6. AUTHOR(S) A.C. Melissinos & W. Donaldson				
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Univ of Rochester Dept of Physics & Astronomy Rochester NY 14627			8. PERFORMING ORGANIZATION REPORT NUMBER AFOSR - TR 90 - 0582	
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) AFOSR/NP Bolling AFB DC 20332-6448			10. SPONSORING / MONITORING AGENCY REPORT NUMBER AFOSR-89-0131	
11. SUPPLEMENTARY NOTES				
12a. DISTRIBUTION / AVAILABILITY STATEMENT Approved for public release; distribution is unlimited.			12b. DISTRIBUTION CODE	
13. ABSTRACT (Maximum 200 words) A 6cm radius, single stage, electron accelerator that uses a photoconductive switch to couple an electromagnetic pulse into a radial transmission line is being developed. The switch consists of a ring of GaAs which is closed with a ring of a laser light from a Phosphate glass regenerative amplifier. We are investigating the acceleration of picosecond electron bunches in fields on the order of several MeV/m. - 244				
14. SUBJECT TERMS			15. NUMBER OF PAGES 12	
			16. PRICE CODE	
17. SECURITY CLASSIFICATION OF REPORT UNCLASSIFIED	18. SECURITY CLASSIFICATION OF THIS PAGE UNCLASSIFIED	19. SECURITY CLASSIFICATION OF ABSTRACT UNCLASSIFIED	20. LIMITATION OF ABSTRACT UL SAR	

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Final Technical Report on AFOSR Contract 89-0131

A Laser Switched Particle LINAC

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W. Donaldson, Laboratory for Laser Energetics

Rochester, New York, 14627

March 27, 1990



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We are working on a proof of principle experiment to accelerate electrons in a radial waveguide structure. A multikilovolt transient with picosecond risetime is coupled into the structure with Silicon or GaAs photoconductive switches which are closed by a Nd:Glass regenerative amplifier laser. The radial waveguide provides voltage gain which ultimately should yield a device with field gradients of several hundred MeV/m. Since the electrons are generated by the same laser from a photocathode the result will be an accelerator which can be used as a high brightness, picosecond bunch length, low emittance electron source. The original concept of such an accelerator is due to W. Willis, and an effort using electron photoemission switches is proceeding at Brookhaven. Radial compression is also being investigated at other laboratories.

Our program at the University of Rochester has been supported in part by the AFOSR and by the DOE. In addition to the principal investigators, Dr. E. Lincke, Mr. T. Blalock, and graduate students C. Bamber and G. Kostoulas are participating in this effort. The immediate goal is to demonstrate that the radial structure provides voltage gain and that it will accelerate electrons at modest voltages. Six months ago our primary laser for the experiment was a Nd:YLF regenerative amplifier, however it became clear that the energy/pulse from this laser was our limiting factor for continuing the project, and we decided it was necessary to fully develop the Nd:Glass regenerative amplifier in our laboratory as our principal laser. Consequently a good deal of our effort over the past few

months has been to make this laser operational. In the past year the following avenues of research have been pursued:

- Two dimensional time-resolved imaging of a closing photoconductive switch.
- Propagation in radial transmission lines.
- Electron emission by short laser pulses.

(i) Equipment and Laboratory Space

Our group is fully moved into our new laboratory at the Laboratory for Laser Energetics (LLE), and most of the capital equipment necessary to complete our project has been acquired. Our laboratory now contains the following:

(a) A Nd:Glass regenerative amplifier. It operates at 5Hz, produces 2-3mJ of IR/pulse, and we are currently working on compressing the pulse width down to the 10ps that our experiment demands with diffraction gratings.

(b) A YLF mode-locked oscillator. The Nd:Glass regenerative amplifier is currently seeded by an oscillator operated by another group at LLE, however we were able to construct our own from surplus parts. We will use it to seed the Nd:Glass regen when we receive the new mode-locker we purchased for it. When it is operational it should produce 50ps pulses at 50MHz.

(c) A 10mm Nd:Glass 4-pass amplifier is on order from Kigre to boost our laser energy another order of magnitude in anticipation of having the capability of firing a multistage device.

(d) We recently took delivery of a new vacuum chamber with more internal operating space, more ports, and the capability of a much lower operating vacuum to replace our old vacuum box.

(e) We have completed our readout system with the purchase of a CCD camera and the appropriate hardware and software to operate it.

(ii) Electro-optic Surface Field Imaging System

This work was carried out by Mr. L. Kingsley and Dr. W. Donaldson. The surface field across the contacts of a switch is mapped in two dimensions and in time with ~ 50 ps resolution. The entire surface is probed during each pulse and it is mapped on a 512×512 array. Furthermore the IR pulse can be used to activate the switch; as a result the collapse of the field, as the carriers migrate across the contacts, can be observed in real time.

The electric field is measured through the electro-optic effect using a LiTaO_3 crystal placed above the contacts. Green light is used in reflection to detect rotation of the polarization; this results in a modulation of the intensity of the reflected beam which is in turn detected by the CID camera. Fig. 1 shows the surface field map with 5 kV bias and no switching. Fig. 2 shows the field at a line across the contracts as a function of time. The switch was activated by the IR pulse at time $t=0$ ps. The switch was made of silicon, had a 3mm gap and 6 kV bias. As can be seen it takes ~ 300 ps before the field collapses completely.

Working with higher voltages Mr. Kingsley was able to study the rise time of a silicon switch subject to a pulsed bias of up to 24 kV. Fig. 3 shows the pulse shape as measured by a capacitive pick-up on a digitizing scope and integrated offline. Fig. 4 shows the rise time as measured by optical sampling; the rise time is of order 200 ps for 10 kV delivered into a 50ω load.

(iii) Propagation in Radial Transmission Lines

Our group has developed compact radial transmission lines on which voltage can be switched by the action of an annular laser pulse. We are exploring two geometries: (i) a semiconductor wafer suitably coated with conducting material forms one of the transmission line boundaries as shown in Fig. 5, (MK I). (ii) Both boundaries are metallic and the semiconductor switch is in the form of a ring at the outer periphery of the structure; this is

shown in Fig. 6, (MK II). We are using both silicon (Si) and gallium arsenide (GaAs) for the switches. In Si the switching is efficient but the hold-off voltage is low. The converse is true for GaAs; we hope to obtain better efficiency in GaAs by increasing the energy in the optical pulse.

The field at the center of the structure is measured by electro-optic sampling which allows us to have picosecond resolution. According to a simple analysis of the pulse propagation in such a structure, the voltage at the center is given by

$$V = 2V_0 \sqrt{\frac{2R_0}{g + c\tau}}$$

where V_0 is the voltage at the outer radius R_0 , g is the gap between the two conducting planes and τ is the rise time of the pulse. During the past year we used a 20 ps laser to study this effect; thus with $R_0 = 3$ cm and $g = 2$ mm we expect a voltage gain $V/V_0 \simeq 5.5$.

Recent results for the MK I structure using a Si wafer are shown in Fig. 7. The peak of the initial pulse arriving at the center is 470 volts and successive peaks occur at a spacing of 150 ps. This is the round trip time between the outside edge of the structure and the edge of the crystal. Since the electro-optic crystal has a dielectric constant $K \sim 49$, only 25% of the pulse amplitude penetrates to the center. Under these circumstances and for an applied voltage $V_0 = 500$ V the data indicate a gain factor $V/V_0 = 4$ in rough agreement with the prediction.

We have also observed pulse propagation with the MK II structure using GaAs, but in this case we don not see gain. We attribute this to a poor coupling from the Blumlein feed into the radial transmission line (impedance mismatch). To study this problem we constructed a linear transmission line with Blumlein injection, the results being shown in Fig. 8. The second pulse appears at 600 psec where the cutoff of the initial pulse should be; this too indicates a poor impedance match, most probably due to only partial switch closing.

The investigation of the radial transmission lines is being continued vigorously and our aim is to understand the behavior of the switches and the propagation in the structure. With the recent completion of the Nd:Glass regenerative amplifier, and the new vacuum box, and the new readout system we expect in the next few months to fully determine the limits and feasibility of these new acceleration concepts.

(iv) Electron Photoemission by Short Laser Pulses

During the past year we successfully produced an electron beam using the Nd:Glass laser pulse. The material was a gold surface and the laser pulse had to be quadrupled in frequency to the U.V. This is achieved by using two doubling crystals. Figure 9(a) shows the measuring set-up and Fig. 9(b) the observed electron pulse. The total charge collected is given by

$$Q = 1.2 \times 10^{-11} \text{C}$$

Thus we find that 7×10^7 electrons were emitted per pulse. The energy in the U.V. was 150 nJ corresponding to an efficiency for photoemission $\eta = 3 \times 10^{-4}$. This is reasonable since the work function for gold is $\phi = 5.1$ eV and the photon energy $h\nu = 4.7$ eV. The illuminated surface was ~ 1 mm² so that our results ($\Delta t = 20$ ps) correspond to an emission of 60 A/cm².

We are now examining other cathode materials, but many of them get easily contaminated in air and therefore require very high vacuum. However the electron yield already obtained is quite adequate for demonstrating acceleration effects. Next we wish to form an electron beam and study its phase space properties using a multichannel plate detector and imaging camera.

(v) Summary of Current Progress and Future Plans

We attempted to accelerate electrons last Fall, however we determined that the Nd:YLF laser we were using was insufficient to fully drive the accelerator so we proceeded

to develop our Nd:Glass regenerative amplifier into a useful laser. We are just completing this now, and are beginning to continue where we left off with the other laser. This new laser has 10 times the energy/pulse and the pulse width is about 10-15ps. We have successfully generated photoelectrons from gold photocathodes with this laser, and we have successfully switched our accelerator device with it. It remains to compress the laser pulse to the 10ps laser pulse width that our experiment demands, and integrate electron generation with electron acceleration. Mr. Kingsley will be completing his doctoral thesis this summer on electro-optic imaging, and Mr. Bamber should complete his doctoral thesis on the accelerator project within the year. In the mean time we have taken on a new student George Kostoulas who will continue the accelerator studies.

Publications and Conference Proceedings under Contract AFOSR 89-0131

1. C. Bamber, W. Donadson, T. Juhasz, L. Kingsley, and A.C. Melissinos, *Particle Accelerators*, 23, 255 (1988).
2. E. Lincke, "Solid State Switching", *Proceedings of the Switched Power Workshop, Shelter Island, BNL-52211, 1988*; Also Univ. of Rochester Preprint ER-13065-576, UR-1109.
3. C. Bamber et al., "Radial Compression of Picosecond Electrical Pulses", *Proceedings of the European Accelerator Conference, Rome, 1988*.
4. C. Bamber et al., "Laser Switched Power Linac", *Proceedings of the Lake Arrowhead Workshop on Advanced Accelerator Concepts, AIP Conference Proceedings No. 193, 1989*.
5. L. E. Kingsley and W. R. Donaldson, "Electro-optic Surface Field Imaging System", *Proceedings of the Pulsed Power Conference, Monterey, CA, 1989*.

Planned Contributions to Future Conferences

1. C. Bamber et al., "Recent Results from the Laser Switched Power Linac", *European Accelerator Conference, Nice, 1990*.

Figure 1

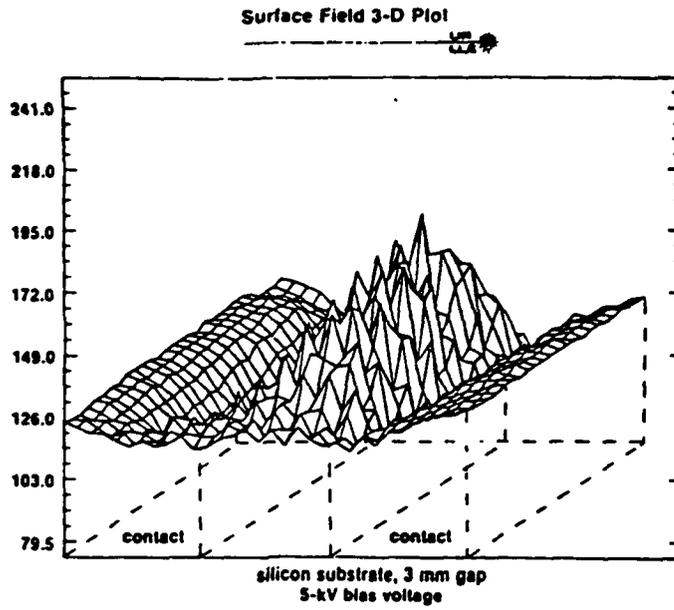


Figure 2

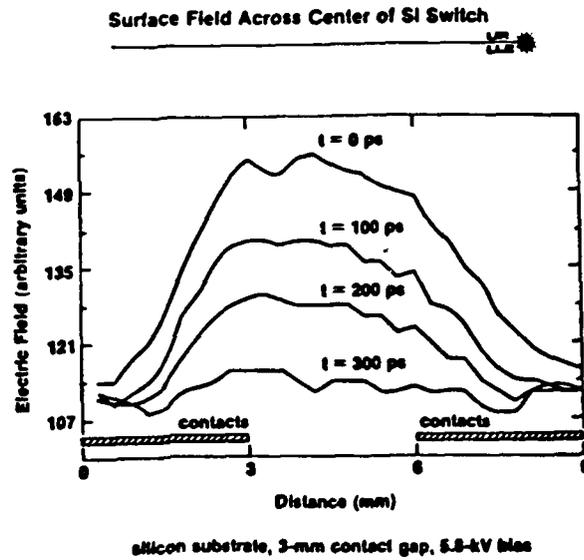
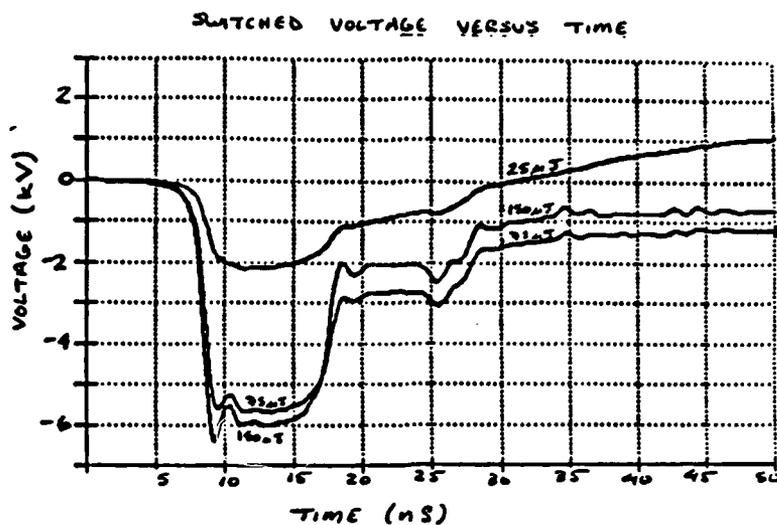


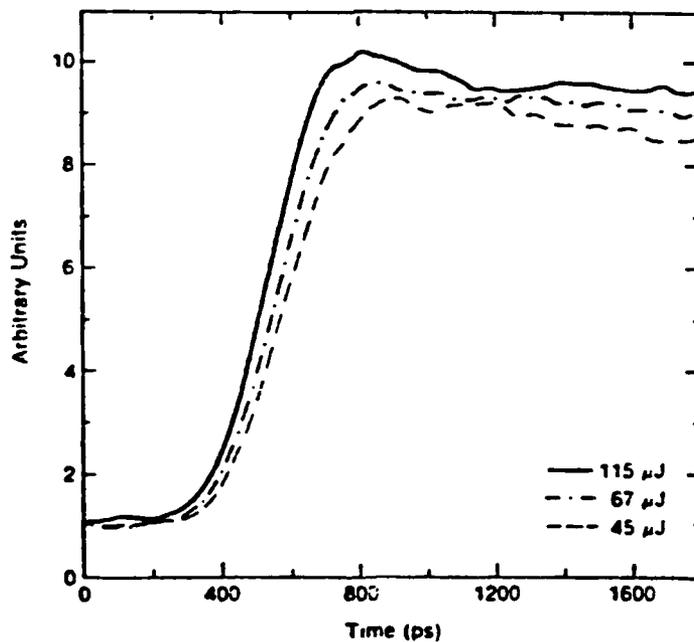
Figure 3



Switching for optical energies of 25, 75, 150 $\mu\text{J}/\text{pulse}$
7 kV input DC to pulser, 17480 V output, ~ 12 kV switch bias

13kV sampling curve.

Figure 4



Accelerating Disc Structure

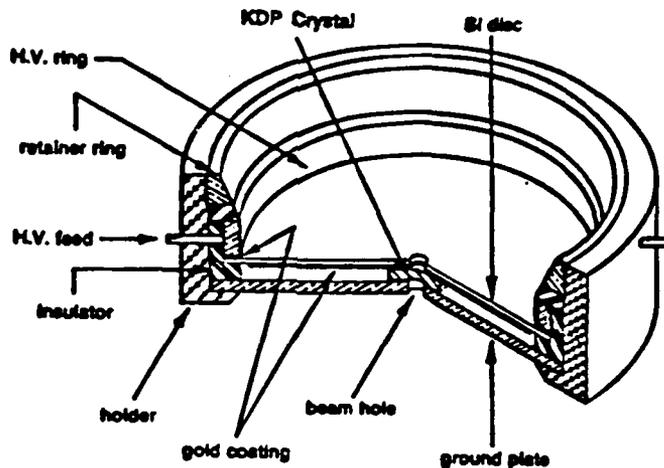


Figure 5

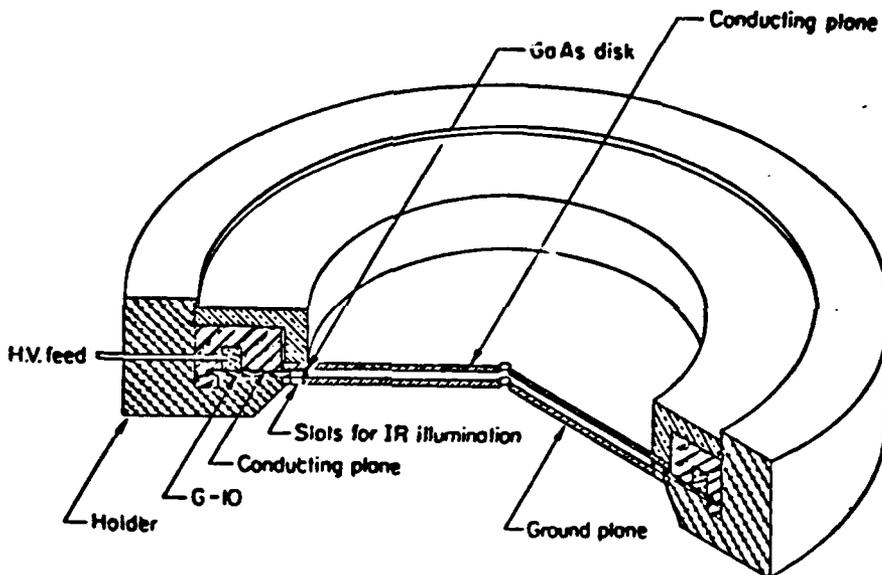


Figure 6

Voltage at Center of Structure

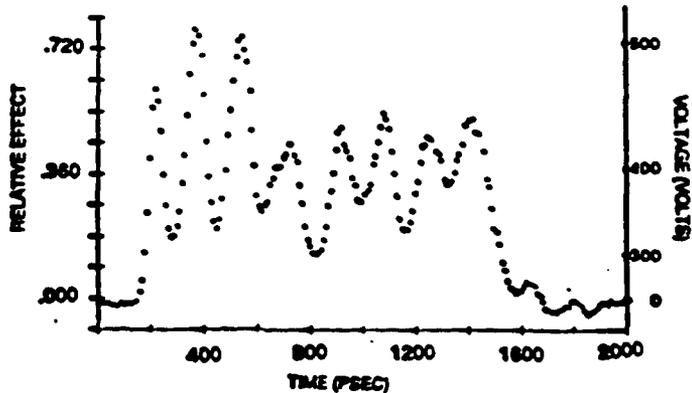


Figure 7

Fig. 8a
Blumlein injection

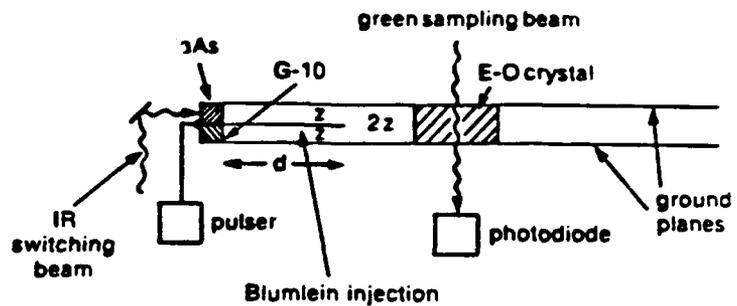


Fig. 8b Blumlein sampling run
with 3" injection line.

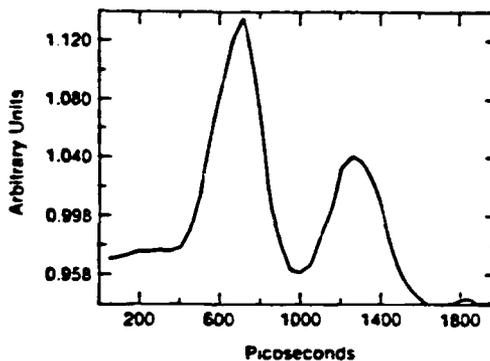


Figure 9a

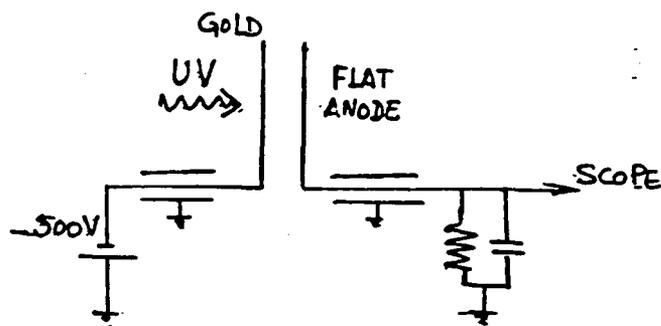
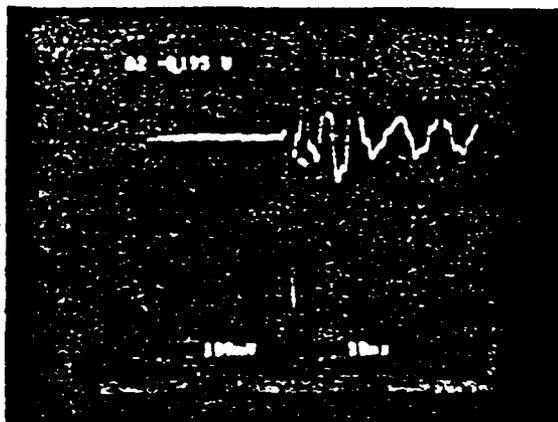


Figure 9b



Synopsis of Equipment Purchased on Grant AFOSR 89-0131

Items Mentioned in Original Request

<u>Item</u>	<u>Manufacturer</u>	<u>Cost</u>
YLF Laser Rod	TJ Sales	3208
RF Amplifier to Drive Mode Locker	Intra Action	990
Optical Fiber	Pirelli Cable	450
Auto Correlator Crystal	INRAD	1600
Oscilloscope	Textronix	5503
Pockells Cell Crystal	INRAD	1845
		<u>\$13596</u>

Vacuum Chamber Upgrade

<u>Item</u>	<u>Manufacturer</u>	<u>Cost</u>
Turbo Pump	Varian	5457
Ion Pump Power Supply	Varian	1815
Ion Gauge Controller	Varian	2213
MCP Electron Detector	Galileo	3902
		<u>\$13387</u>

Laser Upgrade

<u>Item</u>	<u>Manufacturer</u>	<u>Cost</u>
Power Supply	ALE Systems	6880
I.R. Viewer	FIW Optical	1045
Power Supply Cooler	Neslab	2657
2 Pulse Generators	SRS	6625
		<u>\$17207</u>

Electronics Hardware

<u>Manufacturers</u>	<u>Total</u>
Newark, Hewlett-Packard, VWR, McMaster-Car	\$4260

Optics Hardware

<u>Manufacturers</u>	<u>Total</u>
Melles-Griot, Klinger, Glass Fab., Schtt Glass Thor Labs, Vincent Assoc., CVI, Newport	\$7259

Laser Hardware

<u>Manufacturers</u>	<u>Total</u>
Proteus, Barnstead, Laser Applications, ILS, Quantronix, TJ Sales	\$2972

Vacuum Hardware

<u>Manufacturers</u>	<u>Total</u>
MDC, Fredericks, K. Lesker	\$1932

Misc. Parts/Supplies from Misc. Manufacturers \$7587

Total Expenditure \$68200