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PARTICLE AND X-RAY ENERGY MEASUREMENTS IN
LASER-PLASMA INTERACTION EXPERIMENTS*

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ABSTRACT

The energy carried by particles and low energy x-rays resulting from irradiation of targets with .5 to 1 TW, 1.06 μ m lasers has been measured. The energy distributions were obtained from measurements at discrete locations using calorimeters and work is in progress to obtain them over a hemisphere with a thermal imaging system. Azimuthal symmetry and polar distributions for different focusing schemes have been determined. The data have been integrated to obtain the absorbed energy and these values compared to box calorimetry and optical energy balance. The relative emission of low energy x-rays from different Z materials can be obtained by comparing these data to charge collector data. Such comparisons also showed that the effective ion charge can be as low as a factor of two below the completely ionized state. The existence of low charge state ions has since been confirmed with high resolutions spectrometers.

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PARTICLE AND X-RAY ENERGY MEASUREMENTS IN LASER-PLASMA INTERACTION EXPERIMENTS

INTRODUCTION

The integrated particle and x-ray energy flux emanating from laser fusion targets has been measured for a variety of targets and focusing schemes.

Except for experiments solely dedicated to absorption measurements, this flux is determined at a number of discrete locations and a spacial extrapolation is performed to determine the total absorbed energy. Since the precision of the results depends crucially on a proper choice of the distribution fitted to the data, the azimuthal and polar variation of the flux has been investigated.

Differences between distributions resulting from irradiations with $f/1$ and $f/2.5$ focusing lenses have been identified. In particular the polarization dependence suggested by sparse data gathered at the Janus facility has been confirmed for $f/1$ focusing with the more powerful Argus system whereas the weaker effect expected with a higher f number system appears to be masked by non uniformities in the Cyclops beam. Data obtained with ellipsoidal mirrors show little variation of the flux with polar angle resulting from more spherically symmetrical illumination.

Comparison of the data collected with various types of detectors as well as between experimental and theoretical distributions has provided additional insight in the mechanism of laser plasma interaction.

The various aspects of this work will be briefly discussed.

I. THE DETECTORS

Most of the data collected were obtained with differential calorimeters of the reflecting or transmitting type (Fig. 1 and 2). These were described previously¹ and have been fully documented.²

In either case the calorimetric medium absorbs the energy of incident ions, electrons and soft x-rays. In "differential calorimeters" (fig. 1) only 7% of the energy carried by the scattered 1.06 μm radiation is absorbed and this small fraction is cancelled by electrical compensation of two circuits one of which is shielded from all but the light and most energetic x-rays which carry but a small fraction of the total x-ray energy. In "transmitting" calorimeters (fig. 2) the 1.06 μm radiation is mainly transmitted through the calorimetric material, the small absorbed fraction being compensated using in situ calibration factors. The precision of the self compensating calorimeters is limited by the energy absorption efficiency of the absorber. For small signals, another limitation is dictated by the signal to noise ratio. Precisions of the order of 5 to 7% are normally attained. Transmitting calorimeters have a precision of 15 to 20% due chiefly to uncertainties in the correction for absorption of the 1.06 μm radiation.

Although these calorimeters provide a precise measure of the particle and x-ray flux, they only provide data at discrete locations. A new method of obtaining information on the flux distribution over a hemisphere is being developed.

This technique uses a glass bubble surrounding the target. The size of the bubble is such that the incident laser flux is below the glass damage threshold which has been measured at $6.4 \times 10^{10} \text{ W/cm}^2$. The bubble acts as a totally enclosing calorimeter² shield stopping particles and x-rays but transmitting

the scattered radiation. The thermal radiation of the bubble then maps the relative particle and x-ray energy flux. An i.r. vidicon whose sensitivity peaks in the 8 to 10 μm range (fig. 3) is used to obtain a snapshot of the heated glass sphere. Germanium optics shown on figure 3 are used to optimize the radiation intensity in the image plane. The vidicon data are digitized and the proper calibrations applied to transpose the i.r. image into relative energy distribution around the laser fusion target. Initial calibration of the system and development of the associated software are completed. Experiments are now being planned with the ellipsoidal mirror irradiation scheme.

Until a sufficient amount of data are obtained with the "Bubble thermometer", the flux distribution around the fusion targets is obtained principally from the data of the differential calorimeters.

II. ANGULAR DISTRIBUTIONS FROM SPHERICAL TARGETS

Five calorimeters were available for measurements at the Cyclops³ laser facility. Various targets were irradiated with f/2.5 focusing lenses. Results pertaining to microshells will be discussed. A polar* distribution of the particle and x-ray flux is shown on figure 4 and shows a distribution strongly peaked towards the focusing lenses due to the large variations in incidence angle of the light on the target. Ratios as large as 4:1 were observed between calorimeters located at the same azimuthal angle but at polar angles of 30° and 60° respectively. The average value of this ratio for 19 shots at power levels of 200 to 600 GW is 2.2. Symmetry considerations dictate a fit similar to that shown in figure 4. In general curves of the type

$$E_{J/\text{str}} = A + B \cos^2 \theta$$

* See figure 18 for definition of polar and azimuthal angles.

where θ is the polar angle can be used to obtain an estimate of the absorbed energy although computations⁴ show a distortion of the distribution due to inhibited electron conduction resulting from magnetic fields (fig. 5).

Azimuthal variations of this distribution were investigated for the same balls by first comparing two calorimeters located at the same polar angle (60°) but separated by 79° in azimuth. The effect previously observed at Janus with $f/1$ lenses, where, on the average, 2.5 times more energy was observed in the plane of polarization compared to a location normal to this plane was not verified. In the Cyclops case the average ratio of 1.8 was weighted toward the out of plane calorimeter. To further investigate this unexpected result, five calorimeters were all located at the same polar angle, 52.5° from the West beam. Result for several shots with targets where the polarization effect had previously been observed is shown in figure 6. Comparison of the dashed and solid curves dramatically display the danger of curve fitting with an insufficient number of points. The dashed curves are based on four calorimeters whereas the solid curves are based on five. The additional datum forces the major axis of the curves towards 290° to 300° whereas a little imagination resulted in a tilt towards 60° or an almost uniform distribution with four points only. The locations of the calorimeters for the ball shots discussed above are indicated on figure 6. The measured ratio is consistent with the azimuthal distributions shown.

Calculations⁵ made for $f/2.5$ optics and assuming either a fifth power super gaussian or a two-to-one ring beam show a significant change from 1.0 to 1.37 in the fraction of incident energy absorbed by polarization dependent (resonance absorption) to independent (parametric instabilities) mechanisms.

Thus it is apparent that the azimuthal distribution of energy is quite sensitive to the incident beam shape.

The peculiar distributions observed on these Cyclops shots seem to correlate with the intensity profile of the beam which is shown in figure 7 at the equivalent target plane. A fairly repeatable feature (hot spot) was superposed on the ring structure. Moreover the profile varied from fairly circular in the East leg to an occasional rather elliptical distribution in the West leg. The measured energy distribution near the west lens appears to reflect the existence of the hot spot and the beam ellipticity, masking any effect associated with polarization dependent absorption. As discussed later, the distortion of the of the profile due to the target support stalk also contributes to this effect.

As the Janus beam was also far from being cylindrically symmetrical some doubts were raised as to the conclusions drawn from data taken at that facility. These experiments, conducted with f/1 lenses, have now been repeated with the Argus laser system. As shown on figure 8 the Argus⁶ beam has an ellipticity of less than 10% and the light intensity distribution is quite smooth. Typical results obtained with a ball target are shown in figure 9. The particle and x-ray energies measured close to the plane of the light's $\vec{E}$ vector are larger than those measured normal to this plane. This distribution, together with the scattered light distribution⁷ which displays a minimum in the $\vec{E}$ vector plane, confirms the importance of polarization dependent absorption mechanisms such as resonance absorption.⁸ Figure 9 also shows an effect due to the existence of the stalk used to hold the target. A minimum in the energy distribution consistently occurs near $\phi = 0^\circ$. Simulation of the three dimensional expansion in this region is very difficult to perform, so that only a

qualitative picture of the blow off can be drawn. Since the stalk is heated not only by conduction from the target but also directly by the laser pulse, a significant part of it is ionized and expands in the surrounding vacuum. Symmetry considerations show that this expansion will have its major component normal to the axis of the stalk. The micro-shell ions expanding towards $\phi = 0^\circ$ will interact with the low energy stalk plasma, and be slightly deflected away from this region, resulting in the heart shaped distribution shown in figure 9 (Appendix A). At Cyclops the $\vec{E}$ vector lies in the azimuthal plane of the stalk so that competing effects from the stalk and increased flux due to resonance absorption occur.

An additional feature of the energy flux at Argus is shown in figure 10. Here the polar dependance of flux is shown both in the plane of polarization and normal to this plane. The ratio of in to out of plane fluxes varies significantly with polar angle. Since resonance absorption depends on the angle of incidence of the light such a behavior can be expected, but here the presence of the stalk further depresses the distribution in the $\vec{B}$ vector plane.

Details of the flux distribution depend on absorption mechanisms which are intrinsically three dimensional and therefore difficult to include in present hydrodynamic codes. It would, a priori, appear that although the ion distribution is non uniform at the target detectors located thousands of radii away would essentially be seeing a point source of ions so that detracted spatial variations should be minimal. However magnetic fields generated both by the thermoelectric current and as an intrinsic part of the resonance absorption phenomenon⁹ result in a strong inhibition of electron conduction. Electrons channelled by the magnetic field are then responsible for maintaining the anisotropy of the ion distribution. Computations⁴ including only the thermoelectrically generated fields indeed show this effect (figure 5) in the polar ion distribution. Simulations designed to investigate the azimuthal variation due to resonance absorption are in progress.

In summary, measurements made with f/2.5 and f/1 focusing system show that the particle and x-ray energy flux is dependent on the irradiation geometry and for smooth beams resonance absorption and magnetic fields must play a significant role. As a result, extrapolation of a limited number of data points to a total energy cannot rely on computed distributions. Indeed, most codes available to date are not capable of properly modelling these phenomena, although features depending only on total absorbed energy can be accurately predicted.

III. TOTAL ENERGY ESTIMATES

To obtain an estimate of the total absorbed energy on the basis of local measured fluxes, it is necessary to adopt some likely distribution. Our method of computation has been dictated by the number of detectors used and their usual locations. In general three to four detectors are used at a fixed azimuth to provide a basis for estimating the polar distribution according to the $\cos^2$ distribution shown previously. One or two more detectors were used to obtain information on azimuthal variations and the coefficients of the $\cos^2$ distribution are scaled by the corresponding ratio. Figure 11 shows the fit used for the recent Argus data. By using data taken in the $\vec{E}$ vector plane and normal to it, a fairly accurate value of the average energy flux at a fixed polar angle can be obtained (Appendix B) although the perturbation of the distribution due to the stalk results is a bias depending on the relative positions of the stalk and the detectors. A larger error could be introduced by the assumed polar distribution when data cannot be obtained sufficiently close to the axis. On figure 11 for example, doubling the major axis of the distribution would increase the calculated total energy by 20%. Within

these constraints the average absorbed energies for DT filled SiO_2 microspheres are shown on Table 1 and compared with box calorimeter results and light energy balances performed from Si PIN diode data. It should be noted that the light balance particularly for $f/2.5$ focusing, is based on a limited number of detectors so that the same types of uncertainty as discussed for the calorimeters will occur in the integrated scattered light data. Despite the possibility of 20 or 30% errors due to the choice of the fitted curves, these totally different ways of obtaining absorbed energies are in remarkable agreement.

The large differences in absorption between the Cyclop and Argus facilities are predicted by simple models⁵ designed to investigate the effect of beam characteristic on parametric instabilities and resonance absorption. Present knowledge of the beam obtained with these systems result in calculated absorption of the order of 9.6% at Cyclops and 25% at Argus. As previously mentioned these values are very sensitive to the beam parameters so that agreement between the calculated and measured values is quite good.

Table I also includes the absorbed energy inferred from calorimetry for the ellipsoidal mirror system.¹⁰ Here three calorimeters were used, two of the self compensating type located in a plane normal to the incident beam, and the one shown on figure 2 located in the East mirror at 45° from the beam. No large differences were detected between the data from these calorimeters. Indeed in this case the angle of incidence of the light on the target is nearly normal and a fairly uniform distribution is expected. For illumination schemes where the foci of the mirrors were varied from the center of the ball to it's surface the average ratio between the calorimeters located at polar angles of 45° and 90° was

$$\frac{E(\theta = 45)}{E(\theta = 90)} = 1.3 \pm 0.3$$

The value is in good agreement with calculated distributions (fig. 12). From Table I, little improvement in the average fraction of absorbed energy occur between the f/l and ellipsoidal mirror focusing schemes. The advantage of the latter is principally an increase in irradiation symmetry as shown by x-ray micrographs¹⁰.

Figure 13 shows the effect of varying the focusing conditions in the ellipsoidal mirror configuration. Although these data are preliminary due to the limited number of shots available, the general behavior predicted by simulations¹¹ including resonance absorption and parametric instabilities is verified. A maximum in absorption appears to occur when the beam foci are separated by approximately one third of target diameter. The data also confirm that, as the separation of the beam foci increases, the energy distribution lobes along the beam axis increases.

IV. PLANAR TARGETS

Another type of target which has been extensively studied is the planar target¹². A number of experiments were run with the f/2.5 focusing system using irradiation intensities from 10^{12} to 10^{15} W/cm². Large areas of the targets were illuminated with spot diameters of the order of .3 mm. Under these conditions the ion blow off is expected to be almost one dimensional and normal to the target plane. Figure 14 shows a comparison of the measured and computed distribution¹² as a function of polar angle. This figure also shows a comparison between calorimetric data taken at 22° from the $\vec{E}$ vector plane and 22° from the plane normal to it. As

can be seen there are little differences between the data. Figure 15 shows a comparison between these locations for a polar angle of 30° . Because of the planar geometry, and the near normal angle of incidence, any azimuthal dependance of the blow off is expected to be slight compared to the spherical target case, (fig. 15). However in addition to the influence of resonance absorption, a large azimuthal variation of the scattered light distribution ⁷ is expected from Brillouin side scatter.

For this series of experiments, interest was focused on the energy distribution on the incident beam side of the target. No calorimeters were used in the forward scatter direction, so that the total absorbed energy could not be determined directly by this method. Total absorption was obtained from light energy balance as discussed elsewhere⁷, and estimates made from calorimeters data based on computed distributions.

A systematic comparison was made between low and high Z materials to verify the ability of the numerical code used at Lawrence Livermore Laboratory to predict target behavior. For the low Z material, the code predicted that the bulk of the energy would be carried by the ions throughout the range of polar angle investigated. On the contrary for high Z material, a fairly intense low energy x-ray flux was expected. Because the material used (Tungsten Glass) is opaque to its own x radiation, the x-ray flux distribution was expected to follow a $\cos \theta$ distribution dictated by the planar target. The ion flux however would remain nearly one dimensional as shown on figure 14. Hence near the target normal a calorimeter was expected to see mainly ion energy, whereas close to the target plane the x-ray flux would dominate. The effect is qualitatively shown in figure 16. Here a comparison is made between calorimeters and

charge collector data. Charge collectors will measure only ions. However to obtain an ion energy from these data it is necessary to know the time and space dependent charge-to-mass ratio. In the absence of definite information of the latter quantity, a qualitative comparison was made by assuming a constant charge-to-mass ratio which was determined by matching calorimeters and charge collector data at the point closest to the target axis, where the dominant energy component was expected to be ions.* Thus for parylene targets an average value of 3.2 was obtained, implying an average charge of 2 rather than 3.5 for completely stripped ions. With this value the agreement between ion alone and ion + x-ray energies show a negligible x-ray component. On the contrary for Tungsten glass large departures between the distributions show a significant x-ray contribution. Even assuming a 50% error in the charge collector data no acceptable value of $\bar{A}/Z$ could be found to provide agreement between them and the calorimeter data at polar angles larger than 60° since $\bar{A} = 36.6$. The calorimeter data were thus used to obtain an estimate of the low energy x-ray emission by fitting a $\cos \theta$ distribution to the locations closest to the target plane. Departures from this distribution at low θ angles represent the ion contribution. In the planar geometry, this information can be coupled to the computed distribution to yield the total absorbed energy. The value thus calculated for the tungsten glass experiment is of the order of 28%

* Both calorimeters and charge collectors were at 22° from the plane of polarization. However the calorimeters were above the target where the effect of the stalk could result in an underestimate of the target energy, hence an underestimate of $\bar{A}/Z$.

compared to 27% inferred from light energy balance¹². Comparable fractional absorption values are obtained for parylene targets.

For both types of targets the relatively high values of $\bar{A}/Z$ necessary to match charge collector and calorimeter data at small polar angles may be in part due to the large uncertainty in the total energy carried by the very fast ions (> 100 keV/amu). However measurements made with the α spectrometer¹³ for parylene disks at Janus showed the existence of C^{4+} and C^{5+} ions at the megavolt level, and computations for Tungsten glass¹² targets indicate that the tungsten ions are not completely stripped.

A better understanding of ionization kinetics is necessary to interpret charge collector data. In particular the origin of lower charge state, highly energetic ions must still be investigated. A wide band magnetic spectrometer¹⁴ is now in use to obtain accurate values of the total ion energy at the high energy end of the spectrum, and provide more reliable data on the ions' charge state.

CONCLUSION

Polar and azimuthal distributions of the ion and x-ray flux from laser fusion targets irradiated by f/1 focusing lenses show variations compatible with resonance absorption and the existence of large magnetic fields. Total absorbed energy values can be obtained from these data and show average absorptions of the order of 20% for glass microshells. Extrapolations based on computed distributions have been used for planar targets where the x-ray contribution to the calorimeter data may be significant. Good agreement between these data and light energy balances have been obtained.

APPENDIX A

Another experimental fact which can be related to the directional stalk plasma blow off is the absence of very slow (≈ 100 ev/amu) ions in the temporal ion distribution seen at 32° and 46° from the stalk. Figure 17 shows two ion traces taken at a polar angle of 135° but at azimuthal angles of 78.75° and 348.75° respectively (or 26° and 64° from the plane of polarization). On both traces, a first small peak appears at several keV/amu followed by the main plasma component at a few keV/amu. A slight shift towards lower energy for probe B reflects its location further from the $\vec{E}$ vector plane. The most prominent feature is however the very low energy peak seen by probe A which is located at 82° from the stalk whereas probe B is at 46° from it. This low energy peak appears in probes located at angles varying from 79 to 82° from the stalk around the target reflecting the plasma blow off normal to the stalk. It should be noted that less than 1% of the total ion energy is included in this peak so that its absence would not be detectable with the plasma calorimeters.

APPENDIX B

For two sided irradiations of microshells symmetry considerations show that the polar distribution of the particle and x-ray flux should have $dE/d\theta = 0$ at $\theta = 0^\circ, 90^\circ$ and 180° . Here E is the flux in J/sr. A curve of the form

$$E = A + B \cos^2 \theta$$

satisfies this condition and can usually be well fitted to the available data points away from the region of influence of the stalk.

However as shown on figure 10 the flux distribution varies with azimuth, so that the data are better represented by:

$$E = A(\phi) + B(\phi) \cos^2 \theta$$

The total absorbed energy is calculated from*

$$\begin{aligned} E_T &= \int_0^{2\pi} \int_0^\pi [A(\phi) + B(\phi) \cos^2 \theta] \sin \theta \, d\theta \, d\phi \\ &= \int_0^\pi \left[\int_0^{2\pi} A(\phi) \, d\phi + \cos^2 \theta \int_0^{2\pi} B(\phi) \, d\phi \right] \sin \theta \, d\theta \\ &= 2\pi \int_0^\pi \left[\bar{A} + \bar{B} \cos^2 \theta \right] \sin \theta \, d\theta = 4\pi \left[\bar{A} + \frac{\bar{B}}{3} \right] \end{aligned}$$

where $\bar{A}$ and $\bar{B}$ are the ϕ averages of the coefficients A and B .

* This assumes that the total energy in the hemisphere under the influence of the stalk is equal to that in the opposing hemisphere.

For each azimuthal angle ϕ , A and B are obtained by

$$\frac{\partial}{\partial A} \left[\sum_1^N (A + B \cos^2 \theta_n - E_n)^2 \right] = 0$$

$$\frac{\partial}{\partial B} \left[\sum_1^N (A + B \cos^2 \theta_n - E_n)^2 \right] = 0$$

or

$$N A + B \sum_1^N \cos^2 \theta_n = \sum_1^N E_n$$

$$A \sum_1^N \cos^2 \theta_n + B \sum_1^N \cos^4 \theta_n = \sum_1^N E_n \cos^2 \theta_n$$

Hence A and B are linear in E_n

$$A = \sum_1^N \alpha_n E_n$$

$$B = \sum_1^N \beta_n E_n$$

Provided data taken at different azimuth are obtained at the same polar angles the coefficients α_n and β_n are independant of ϕ , and

$$A(\phi) = \sum_1^N \alpha_n E_n(\phi) \quad \rightarrow \quad \bar{A} = \sum_1^N \alpha_n \bar{E}_n$$

$$B(\phi) = \sum_1^N \beta_n E_n(\phi) \quad \rightarrow \quad \bar{B} = \sum_1^N \beta_n \bar{E}_n$$

so that the total energy becomes linearly dependant on the ϕ averages of the measured flux at each polar angle. If a sufficient number of points would be obtained to properly define the azimuthal distribution a curve could be fitted to the data and an appropriate average obtained.

In practice, most of the experiments provided only two values, one in ($E_{\parallel}$) and one normal to ($E_{\perp}$) the plane of polarization of the incident radiation. Again, assuming symmetry (and ignoring the effect of the stalk) curves of the type

$E(\phi, \theta = \text{cte}) = C + D \cos^2(\phi - \phi_0)$ $\phi_0 =$ azimuth of the $\vec{E}$ vector
could be used, in which case the parameters would be;

$$E(\phi, \theta = \text{cte}) = E_{\perp} + (E_{\parallel} - E_{\perp}) \cos^2(\phi - \phi_0)$$

Then $\bar{E} = \frac{E_{\parallel} + E_{\perp}}{2}$

This value has been used throughout the absorbed energy estimates.

Recent work at Argus shown however that the effect of the stalk is to depress the distribution near $\phi = 0$ so that $E_{\perp}$ is underestimated by this method since the calorimeters were located at $\phi = 11.25^\circ$ and 231.55° respectively. As more data on the actual distribution are available, a better average will be obtained.

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FRACTIONAL LASER LIGHT ABSORPTION FOR BALL TARGETS

Focusing scheme	Calorimetry ^a	% absorbed box calorimeter	PIN diodes ^a	Incident power range
f/2.5 lenses (CYCLOPS)	13 ± 4	13 ⁺⁹ ₋₅ ^b	15 ^b	200 – 700 GW
f/1 lenses (ARGUS)	22 ± 4	27 ± 3 ^c	21 ± 4	1 – 3 TW
Ellipsoidal mirrors (≈ f/0.077)	20 ± 3	—	—	150 – 450 GW

a. Errors indicated include only deviation from the mean

b. Only one datum available

c. Data taken at JANUS – 250 to 500 GW range

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TABLE I

FIGURE CAPTIONS

1. LC-17 Self Compensating Particle and X-Ray Calorimeter.
The output of the calorimeter is a measure of the differential heating between the disk and ring absorbers which have equal sensitivities to incident energy fluxes.
2. LC-25 Transmitting Calorimeter.
The absorber is transparent to $1.06 \mu\text{m}$ radiation. The small size of this instrument makes it convenient for use where space is limited. It is seen here in a mounting fixture designed for use in the Janus ellipsoidal mirrors.
3. "Bubble Thermometer" Experiment.
The particles and low energy x-rays heat a surrounding glass bubble. The far i.r. (8 to $14 \mu\text{m}$) radiation from the heated bubble provides an image on an i.r. vidicon whose video signal is digitized and processed to obtain hemispherical particle and x-ray distribution.
4. Polar Energy Flux Distribution for a Microshell Illuminated with an $f/2.5$ Focusing System.
The measured flux shows a large maximum towards the lenses. The pronounced minimum at 90° is a signature of the stalk.
5. Computed Polar Distribution for Microshells.
The magnetic field resulting from thermoelectric currents distort the ion distribution.
6. The Azimuthal Energy Flux Distribution at the Cyclops Facility is Tilted about 60° from the Plane of Polarization. ($\theta = 52.5^\circ$). Lines indicate the locations of calorimeters used for preliminary studies of the azimuthal dependence of energy flux.
7. The Cyclops Beam has a Fairly Uniform Ring Distribution. However "Hot Spots" (upper left and to a lesser extent lower right on the time integrated photograph) occurred fairly consistently.
8. The Argus Beam is fairly uniform with random intensity modulations even at very high power.
9. The azimuthal particle and x-ray flux distribution at Argus show a definite polarization dependence, modified by the existence of the stalk. ($\theta = 105^\circ$)
10. The polar dependance of the flux is modified by the azimuthal angle and the existence of the stalk.
11. The average flux value between in and out of the polarization planes is fitted to a $\cos^2$ curve versus polar angle to estimate total absorption.

FIGURE CAPTIONS cont.

12. With ellipsoidal mirrors irradiating a microshell over 84% of 4π computations and experimental data show little variation in energy flux. A typical fit used for experimental data show excellent agreement with the computed curve.
13. Preliminary data confirm the existence of an optimum focii overlap for maximum absorption with ellipsoidal mirror focusing.
14. Both theory and experiments show a nearly one dimensionnal ion blow off for planar parylene targets irradiated with f/2.5 focusing optics. Comparison of calorimetry and charge collectors show a good fit for $A/Z = 3.2$.
15. At Cyclops little variation of the particle and x-ray energy flux with azimuthal angle occurred for planar target by contrast to the much larger variation for microshells.
16. Comparisons between calorimetry and charge collector data show a significant x-ray flux for high Z targets.
17. Charge collector data show a very slow plasma component in the plane normal to the target stalk. The cylindrically expanding plasma from the stalk yields no component at 46° .
18. Polar angles are measured with respect to the beam axis (West beam at Janus and Cyclops, North beam at Argus). Azimuthal angles are measured counter clockwise in a plane normal to this axis. Zero azimuth corresponds to the upwards pointing vertical.

**THE DUAL ABSORBER CONSTRUCTION ALLOWS CANCELLATION OF THE
SMALL (7%) FRACTION OF $1.06\ \mu\text{m}$ RADIATION ABSORBED**

Figure 1

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Figure 2

Figure 3

Shot 56022503

Figure 4

Microshell target — 1.25 TW peak power

Figure 5

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f/2.5 focusing

Classification - NOTE:
although it is not mentioned
some of the data here comes
from classified shots.

Figure 6

Time integrated photo

Streak camera photo

Figure 7

**Array camera record
time integrated**

**Streak camera record
time resolved**

Shot 36060801

70 Joules

63 psec

1.1 tw

7×10^7 neutrons

158 microns inside f/1 focus

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Figure 8

Shot 36091408

Figure 9

Shot 36080611

270

Figure 10

Shot 36080507

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Figure 11

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Figure 12

Figure 13

The charge collector data were normalized to the calorimeter value at $\theta = 150^\circ$,
 implying $A/Z = 3.25$

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Figure 14

f/2.5 focusing optics

Figure 15

Figure 16

Sweep speed $0.5 \mu\text{s/cm}$

A @ 0.2 v/cm

B @ 0.5 v/cm

Figure 17

Figure 18