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INTERNATIONAL CENTRE FOR THEORETICAL PHYSICS
34100 TRIESTE (ITALY) - P.O.B. 586 - MIRAMARE - STRADA COSTIERA 11 - TELEPHONE: 2240-1
CABLE: CENTRATOM - TELEX 460392 - I

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SPRING COLLEGE ON PLASMA PHYSICS

(25 May - 19 June 1987)

ENERGY TRANSPORT AND SYMMETRY CONSIDERATIONS IN HOT ELECTRON MICROEXPLOSIONS DRIVEN BY A CO_2 LASER

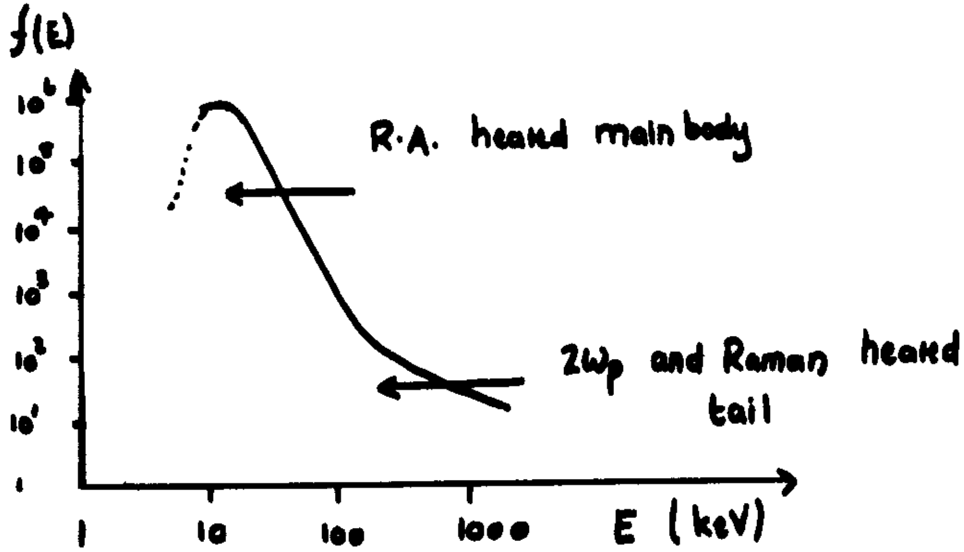
C. JOSHI
University of California
U.S.A.

Energy Transport and Symmetry Considerations in Hot Electron Microexplosions Driven by a CO_2 Laser

C. Joshi (UCLA)

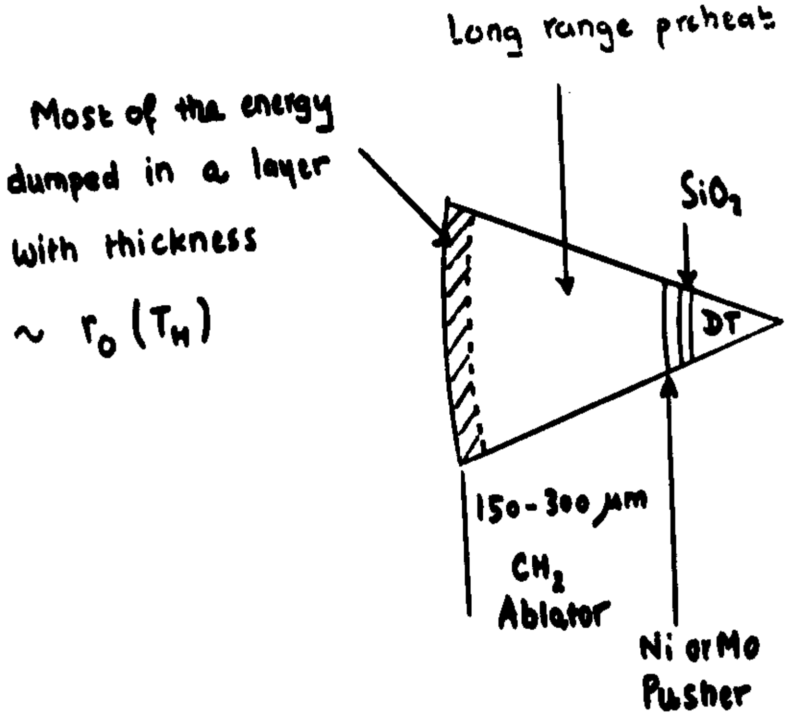
Work done in collaboration with
D. Villeneuve, P. Jaanimagi, N. Ebrahim and N. Burnett
National Research Council of Canada.

At high intensities, $v_0/v_T \gg 1$, collisionless absorption mechanisms deposit most of the absorbed laser energy into hot electrons.



Typical Heated Electron Distribution at $I\lambda^2 \sim 10^{16} - 10^{17}$ $W/cm^2 \cdot \mu m^2$

Ref - Phys. Fluids 24, 138 (1981)
– Ebrahim and T...



Typical Quasi Ablative Target for CO_2 fusion

Ref. Fries, Kopp, McCall and Tan
LA-UR-79-761

FACTORS WHICH INFLUENCE UNIFORMITY OF ENERGY DEPOSITION

i) Spread of angular momenta of the resonantly accelerated electrons

ii) Scattering of the hot electrons in the cold dense target

iii) Deflection of the corona electrons by the magnetic fields in the underdense plasma

iv) Scattering of the corona electrons by the target and plasma potentials.

OUTLINE OF THE TALK.

Main findings of the experimental work on energy transport by hot electrons for $10^{15} < I\lambda^2 (W/cm^2 \cdot \mu m^2) < 10^{17}$ are that the interaction physics is dominated by

i) a small no. of very high energy electrons that escape the target ;

- Phys. Fluids 24, 138 (1981)

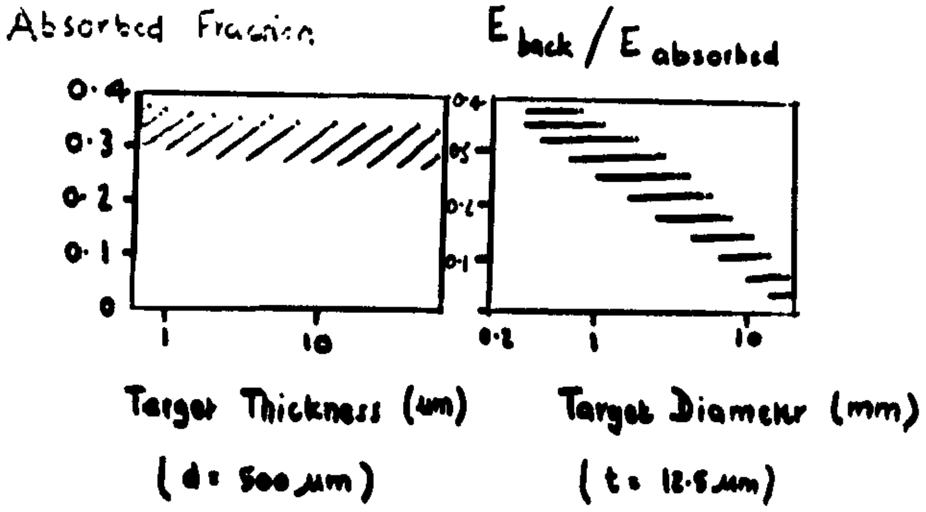
ii) resonantly accelerated electrons that orbit the superthermal corona

- Phys. Rev. Lett 43, 1995 (1979)
- App. Phys Lett, May (1981)

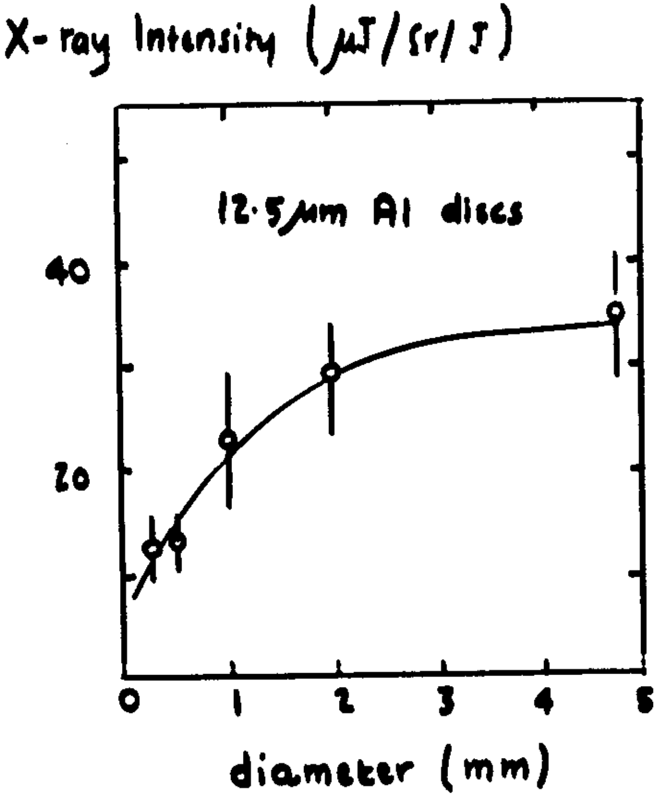
iii) hot electrons that are reflected by the ambipolar and ponderomotive potentials near n_c

- UCLA PPG (1981) to be published
- App. Phys. Lett. 38, 226 (1981)

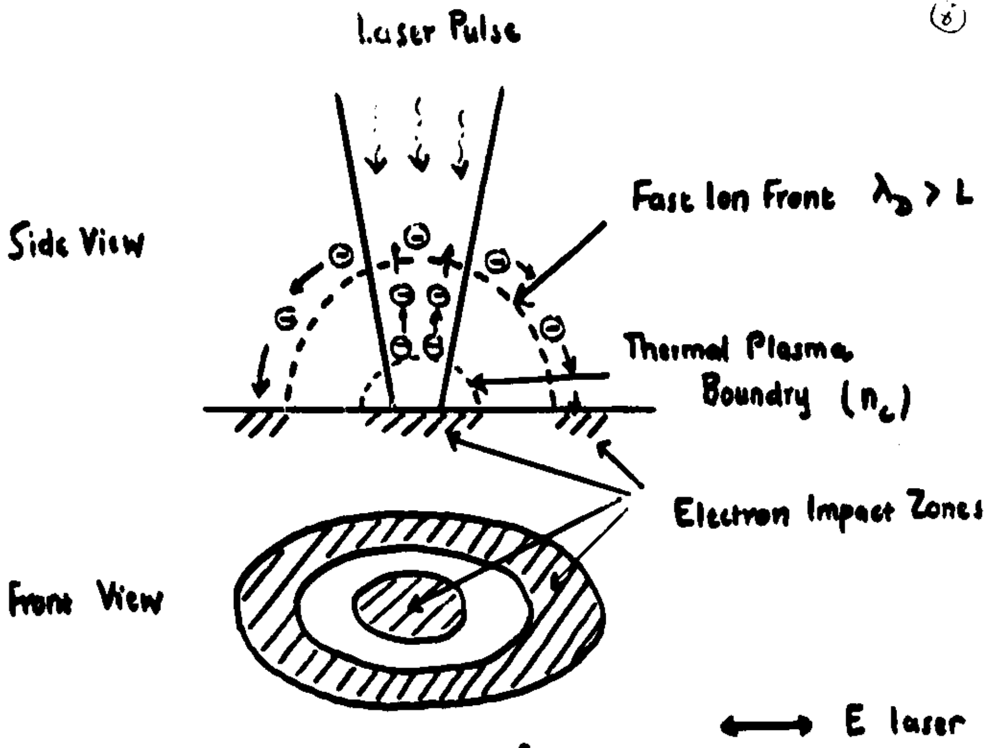
ANOMALOUS TRANSPORT TO REAR SURFACE OF MICRODISCS



- Absorption was independent of thickness, Z or diameter
- Partitioning of the absorbed energy between the front and the rear blow-offs was strongly diameter dependent.
- Detailed diagnostics showed that energy in the rear plasma was transported around rather than through the target

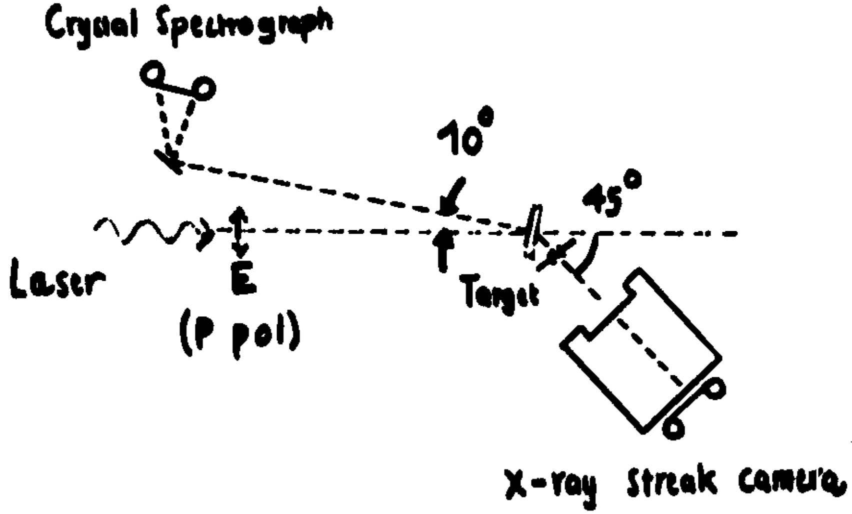


- Integrated hard X-ray flux ($E > 5$ keV) was strongly diameter dependent
- K_α and fast-ion emission from the rear side of targets (too thick to allow any significant hot electron transport through them) confirmed the role of orbiting hot electrons in transporting energy around the target.

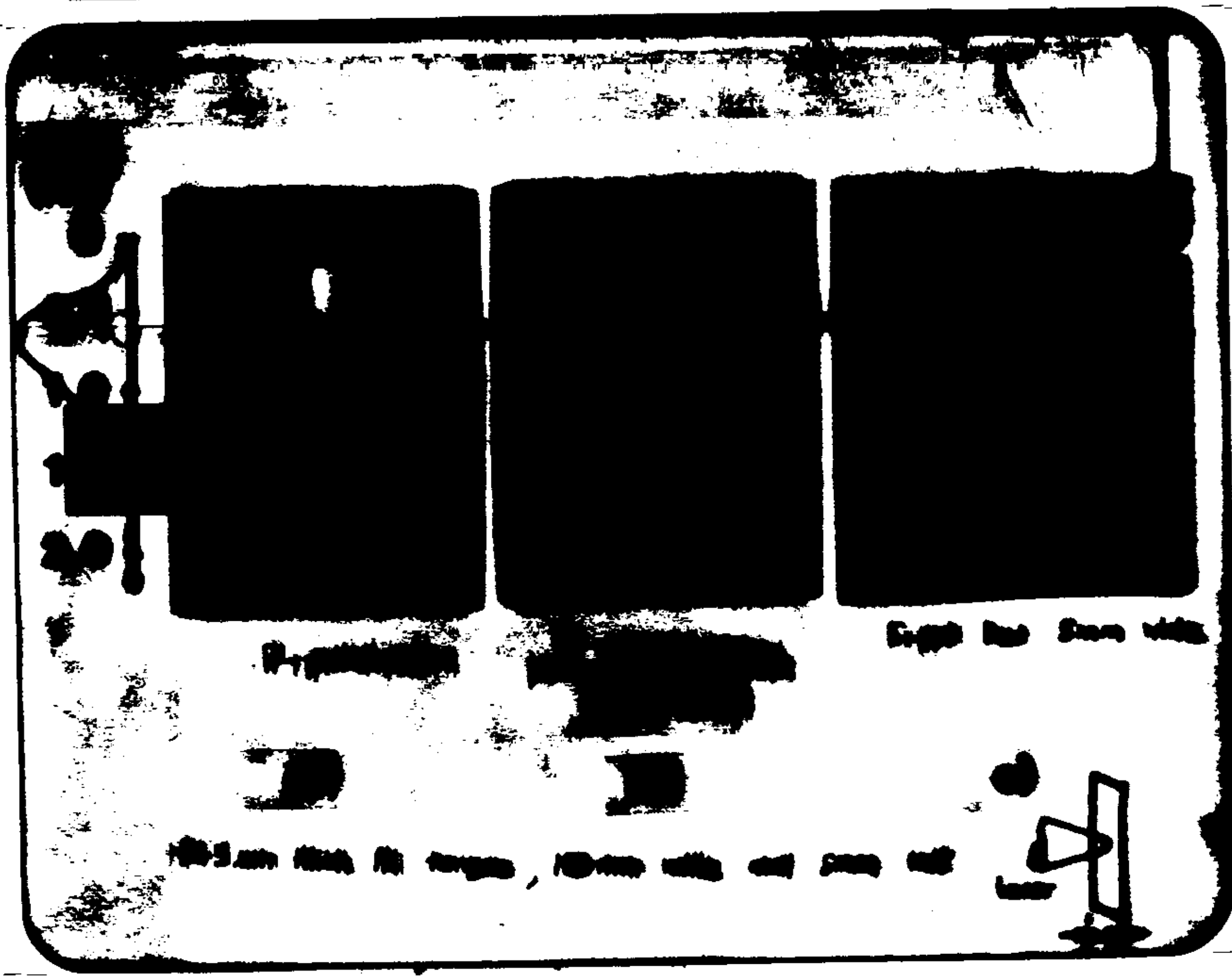


- For $I\lambda^2 \sim 10^{17}$ W/cm$^2\cdot\mu$m^2, $E^2/8\pi n_c T_H \sim 1$ and hot electrons are partially contained by the ponderomotive force
- Electrons able to overcome this potential barrier at n_c cause fast ion expansion.
- Fast-ion front arises because charge seperation truncates the exponential density profile where $\lambda_D > L$.
- Ahead of the fast-ion front exists a cloud of pure electron gas confined by the target potential.

DIRECT EVIDENCE FOR RETURN CURRENT ELECTRON STREAMS



- X-ray emission from the front and rear of foil targets was spatially and temporally resolved with an X-ray streak camera
- Crystal Spectrograph (RAP) was used to obtain spatially resolved but time integrated K_α profiles.
- CO_2 pulses 35-55 J were focussed to ~ 125 μm spots on 1-5 mm diameter Al foil targets.



GEMINI

Main Features of Space-Resolved X-ray Streak Pictures

- Polarization dependent asymmetry

  P-polarization expansion velocity 10^9 cm s^{-1}

  S-polarization 5×10^8 cm s^{-1}

- Expansion velocities consistent with the maximum fast-ion velocities (protons) in these experiments

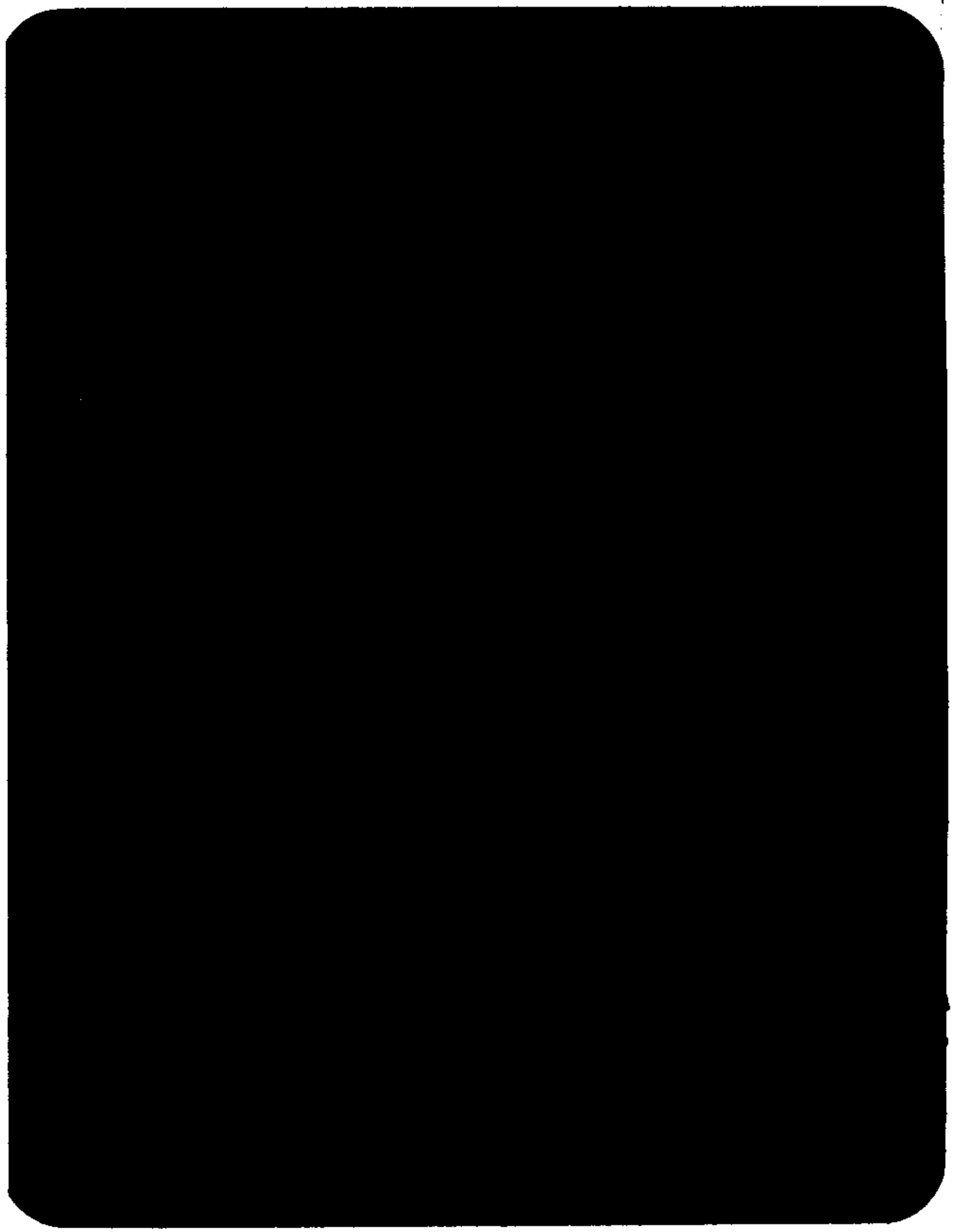
- X-ray emission weakly dependent on target thickness (suggests K_α)

- X-ray streaks strongly suggest polarization asymmetric return current streams of hot electrons.

- Macroscopic current loop may be giving rise to a large B field

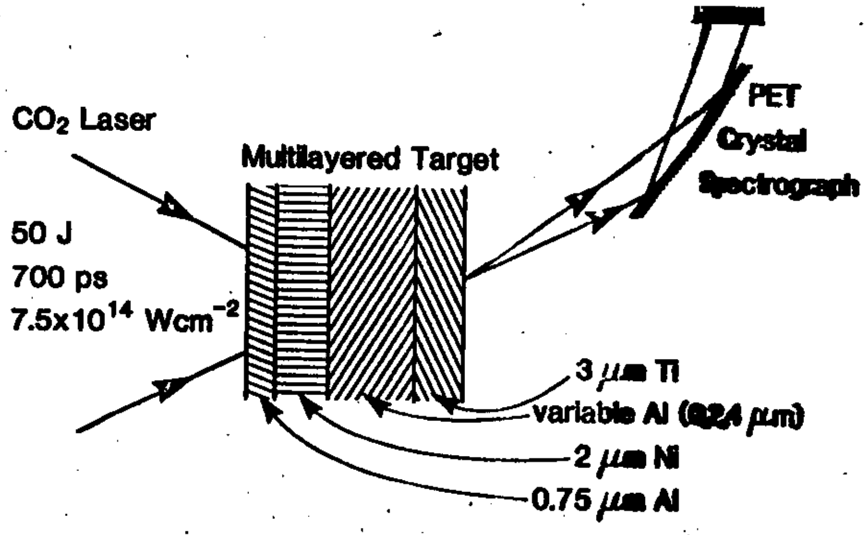
  Sakagami et al - Phys. Rev. Lett <u>42</u>, 839 (1979)

  Kolodner and Yablonovitch - Phys. Rev. Lett <u>43</u>, 1402 (1979)



Measurement of Target Preheat by Hot Electrons.

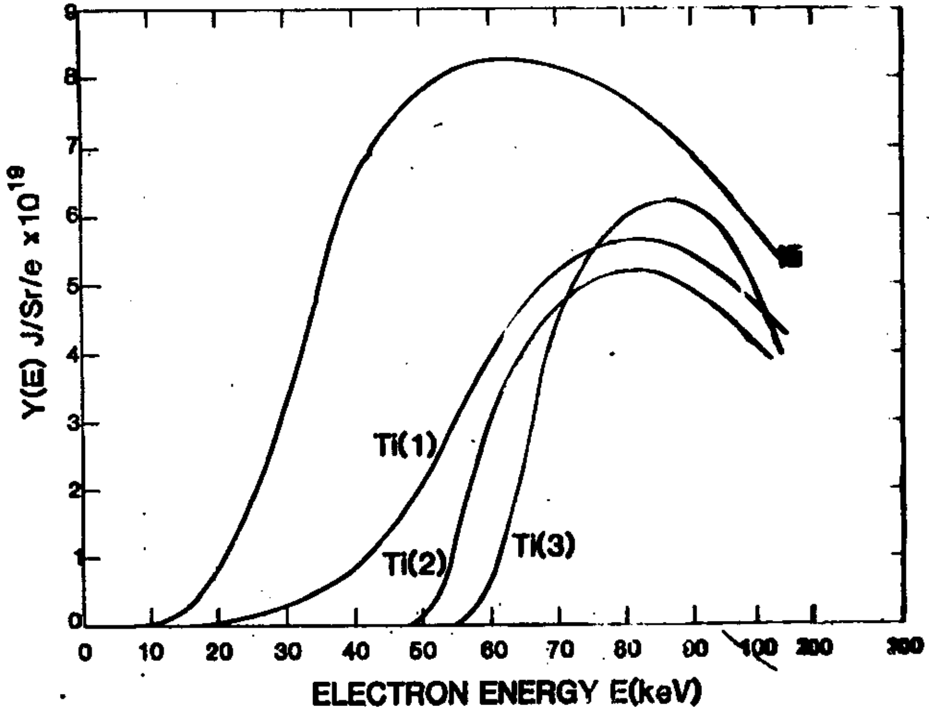
EXPERIMENTAL ARRANGEMENT



0·75 µm Al :- Ablator Layer
Produces a plasma of known absorption, x-ray, fast ions and electrons characteristics.

Ti and Ni Fluor Layers Energy Analyse the Electron Distribution.

K_α Yeild per electron

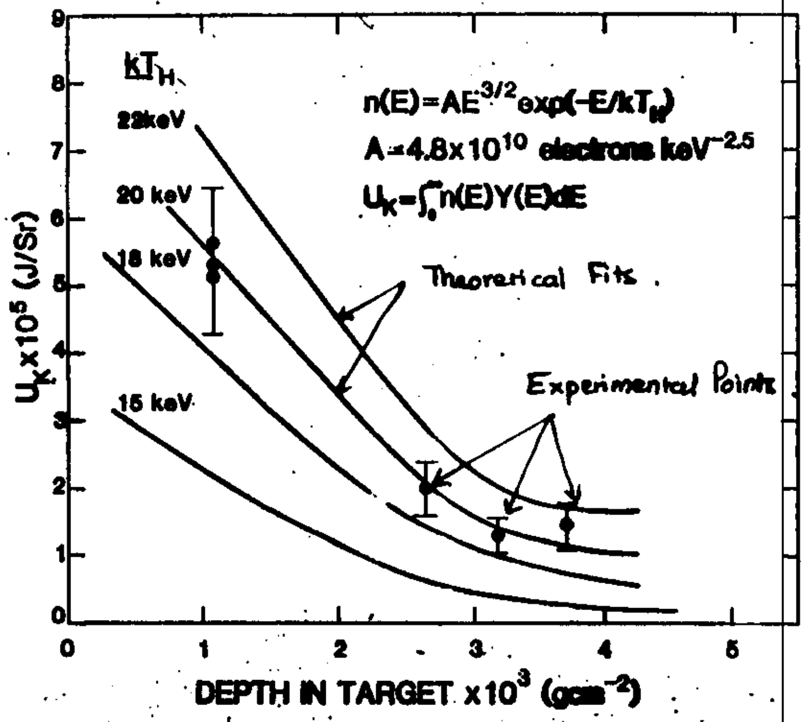


$$Y(E) = \frac{1}{4\pi} \frac{E_{K_\alpha}}{E_K} \omega_K R(E) \, dE \qquad J/sr/e.$$

$$U_K = \int_0^\infty Y(E) f(E) \, dE \qquad J/sr.$$

Assume $f(E) = A E^{N/2} \exp\left(-E/kT_H\right)$

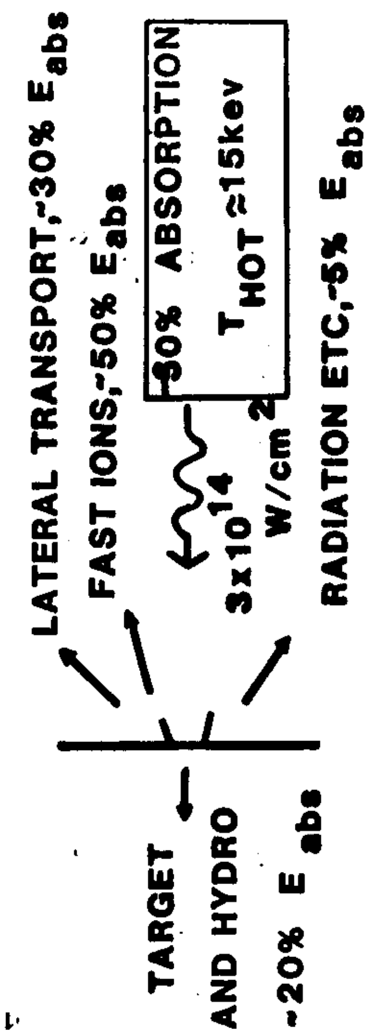
And choose parameter A, N and T_H such that the experimentally observed yields fit the calculation.

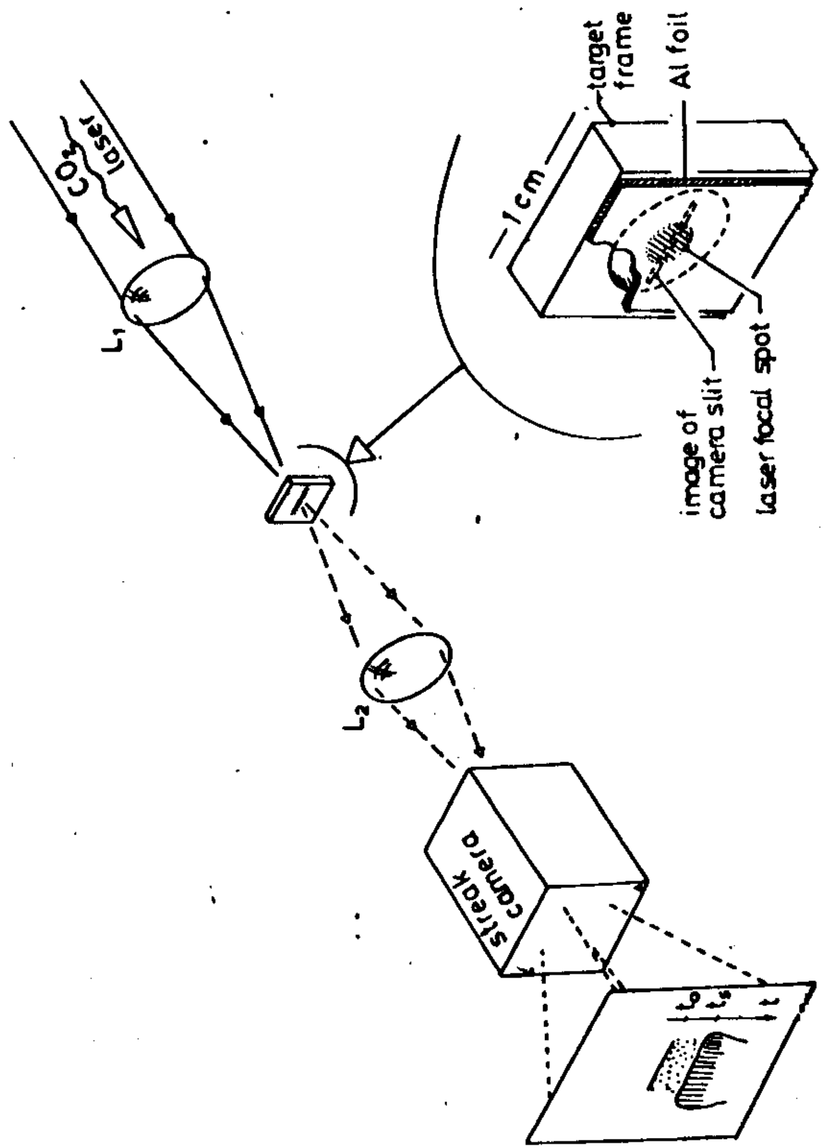


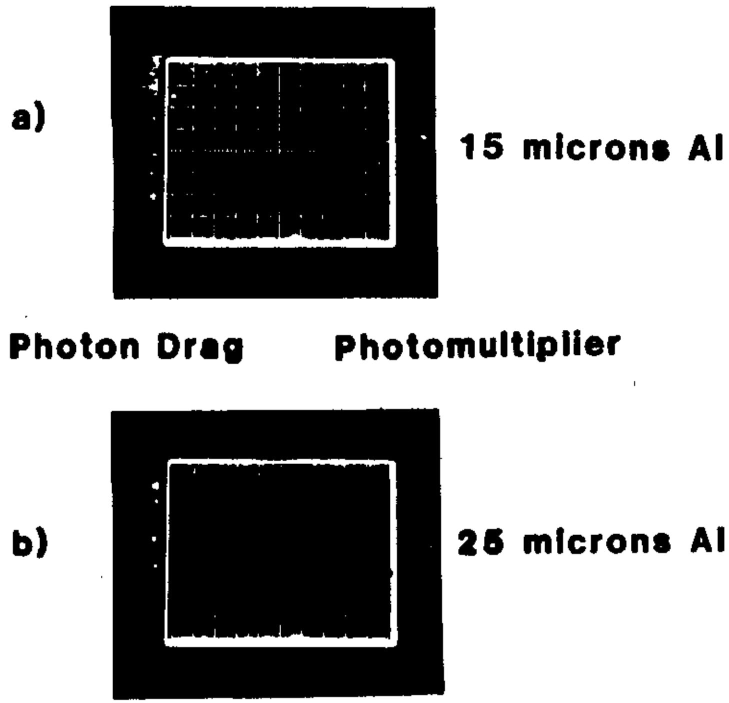
The total preheat

$$E_p = A \int E^{N/2+1} \exp\left(-E/kT_H\right) dE$$

APPROXIMATE ENERGY PATHS IN HIGH INTENSITY CO_2 LASER IRRADIATION OF LARGE DIAMETER TARGETS APPEAR TO BE AS FOLLOWS



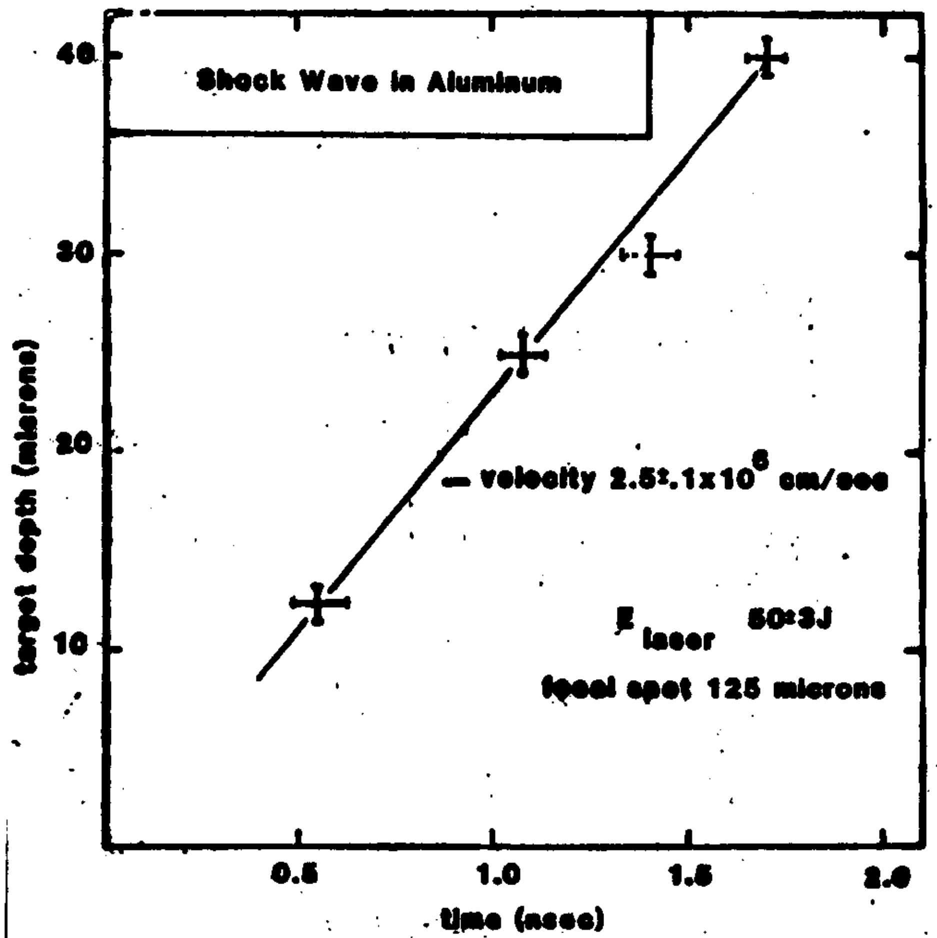

CO2 laser
L1
L2
1 cm
target frame
Al foil
image of camera slit
laser focal spot
streak camera
t0
ts
t

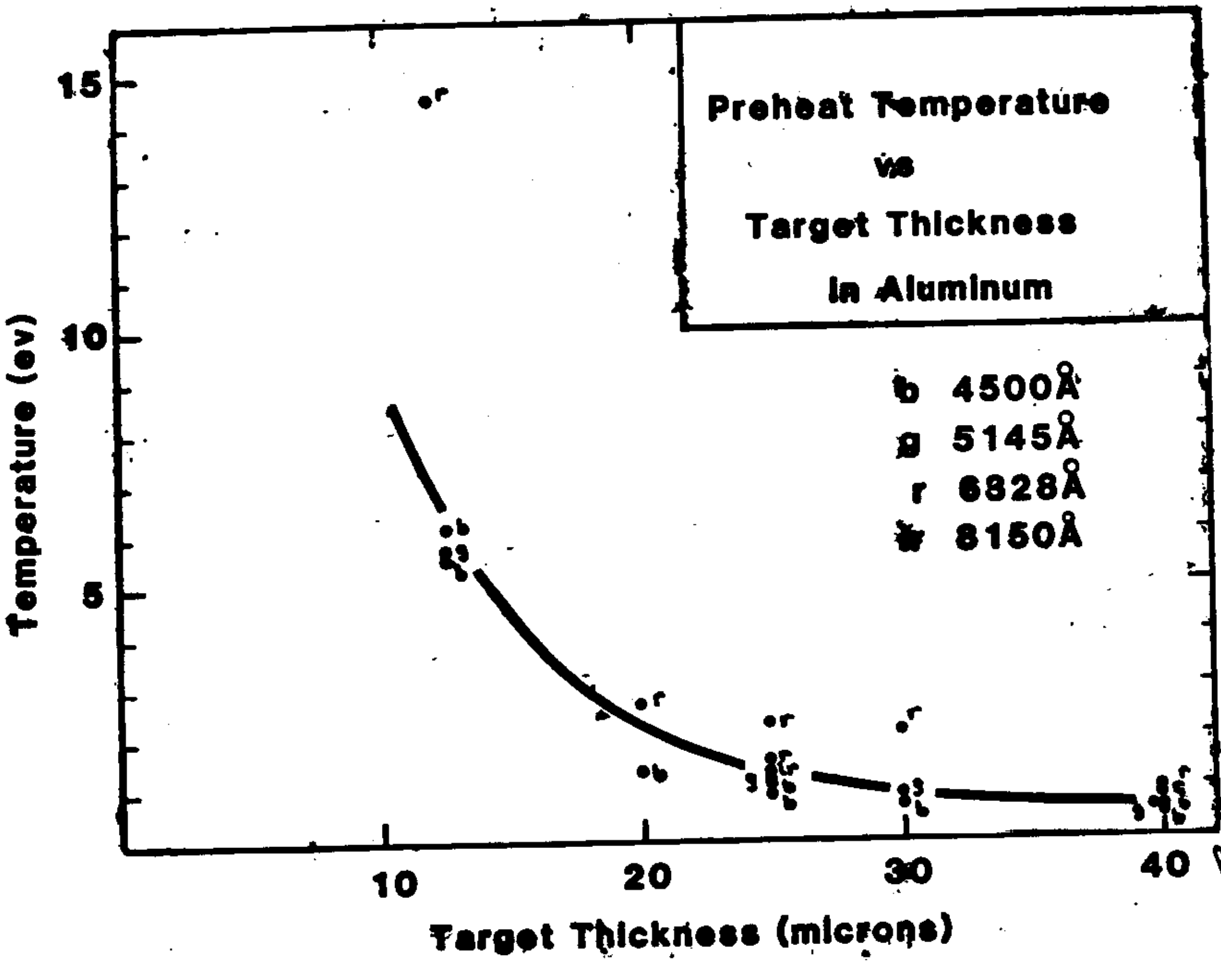

a)
15 microns Al
Photon Drag
Photomultiplier
b)
25 microns Al

- THE SHOCK WAVE VELOCITY ($> 2 \times 10^6$ cm s^{-1}) OBSERVED IN THESE STUDIES IMPLIES A SHOCK PRESSURE OF ABOUT 10 Mbar, COMPARABLE TO SHOCK PRESSURES REPORTED FROM 1 μm EXPTS AT SIMILAR IRRADIANCE.

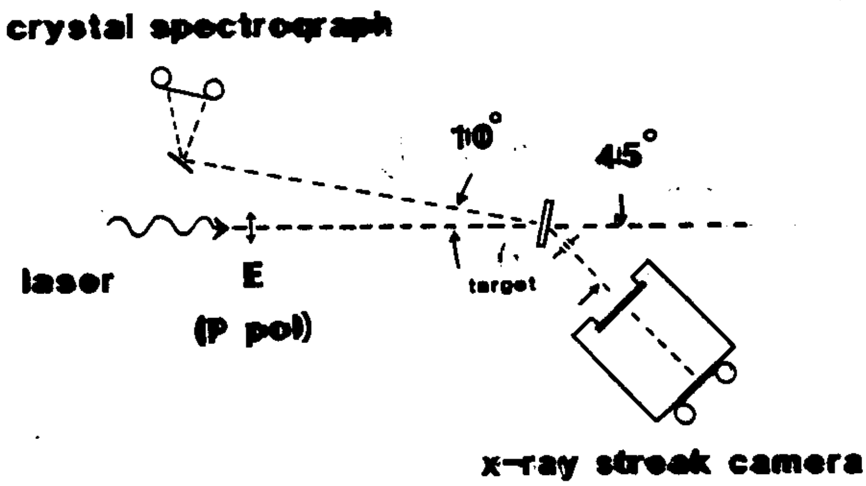
- IN THE PRESENT CASE WE BELIEVE THAT THE SHOCK WAVE IS GENERATED BY HOT ELECTRON HEATING AND THE SUBSEQUENT EXPLOSION OF A SURFACE LAYER OF Al SEVERAL MICRONS THICK WHICH THEN DRIVES A BLAST WAVE THROUGH THE REMAINING MORE WEAKLY PREHEATED TARGET MATERIAL.

- THE OBSERVED SHOCK OR BLAST WAVE VELOCITY CAN BE DUPLICATED IN A SIMPLE 1D FLUID CODE BY ASSUMING THAT 15% OF THE INCIDENT LASER FLUX IS USEFULLY COUPLED INTO THE TARGET THROUGH A 20 keV MAXWELLIAN HOT ELECTRON DISTRIBUTION OVER A 250 μm DIAMETER DEPOSITED CLASSICALLY.




Preheat Temperature
vs
Target Thickness
in Aluminum
b 4500Å
g 5145Å
r 6828Å
8150Å
Temperature (ev)
15
10
5
10
20
30
40
Target Thickness (microns)

22


crystal spectrograph
10°
45°
laser
E
(P pol)
target
x-ray streak camera

#23