

# Laser plasma researches in Hungary related to the physics of fast ignitors

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# Content

1. Activities in the HILL Laboratory
  - nonlinear interactions, high harmonics generation
  - spectroscopy, isochoric heating
2. Collaboration with the MPQ, Germany:
  - fast electron generation in a preformed plasma
  - propagation of fast electrons in solid matter
3. Trends and some new results in fast ignitor physics

# The HILL Laboratory

## *(High Intensity Laser Laboratory)*

A joint project of the Department of Physics of the University of Szeged  
(Sándor Szatmári, J. Bohus, short pulse ultraviolet lasers)

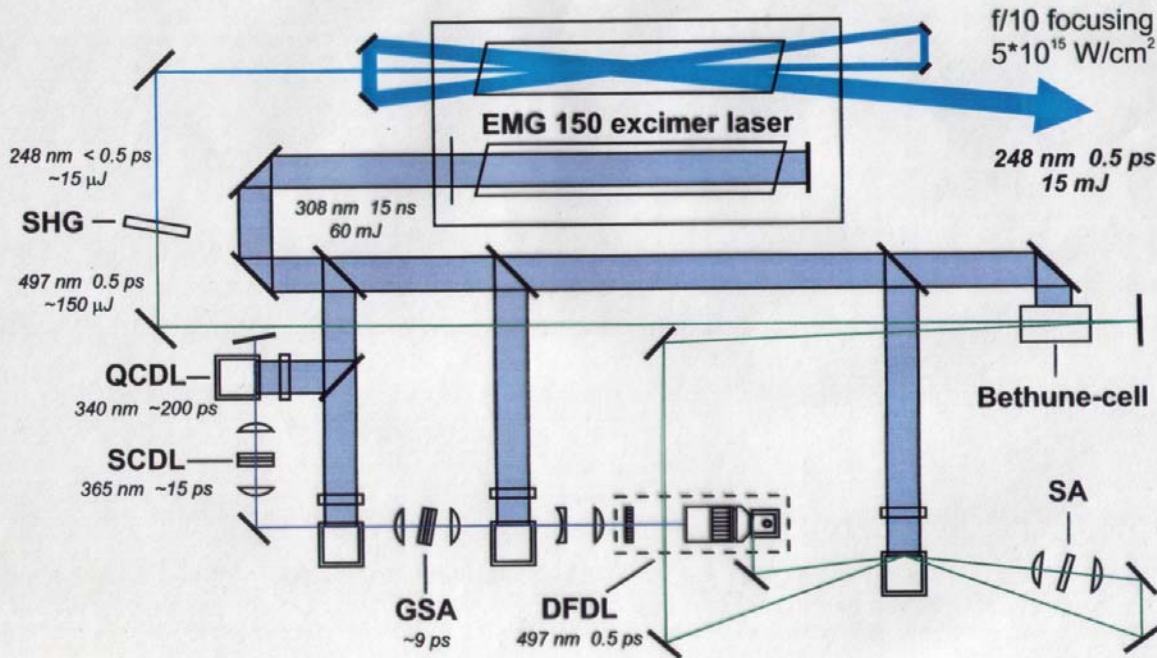
and the

Plasma Physics Department (Association EURATOM) of the  
KFKI-Research Institute for Particle and Nuclear Physics  
(Plasma Physics Department) in Budapest

(István B. Földes, G. Kocsis, E. Rácz, G. Veres

Laser plasma interactions, plasma diagnostics)

## The KrF laser system



- $\lambda = 248 \text{ nm}$
- $\tau = 600 \text{ fs}$
- $E = 15 \text{ mJ}$

prepulses only from ASE  
(ns duration)

ASE intensity:  $10^7 \text{ W/cm}^2$

## Planned upgrade: 50-100 mJ

## Main use of the laser: laser plasma experiments

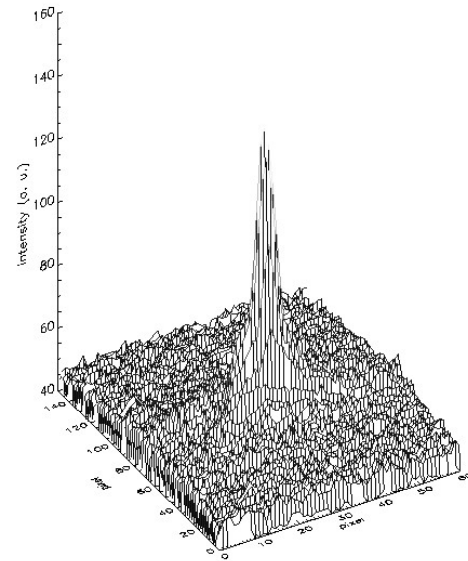
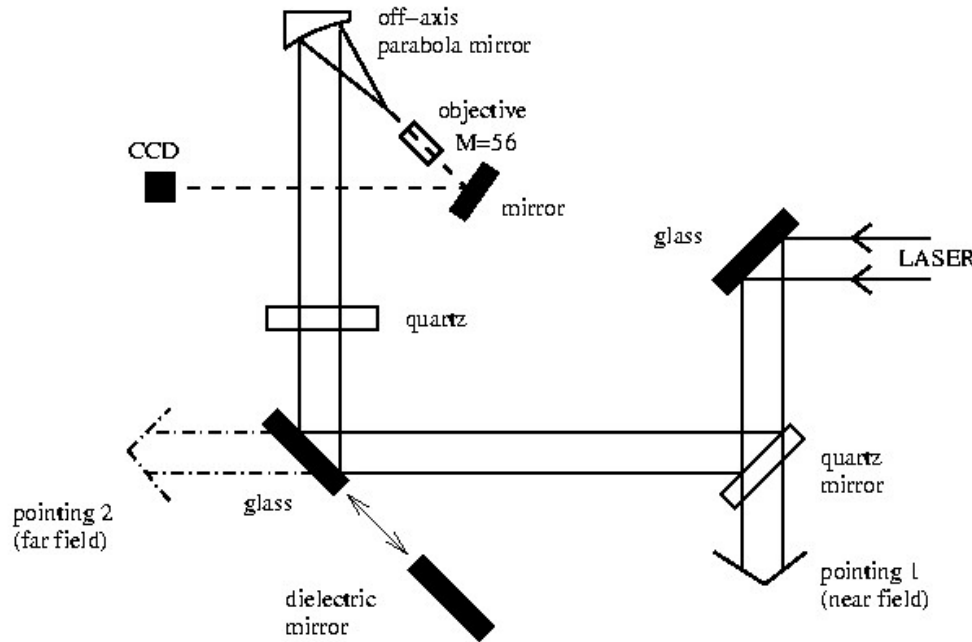
## Other applications: ablation, solid surfaces

also with nanosecond pulses (1 J, 10-20 ns)

# High-intensity experiments with tight focusing

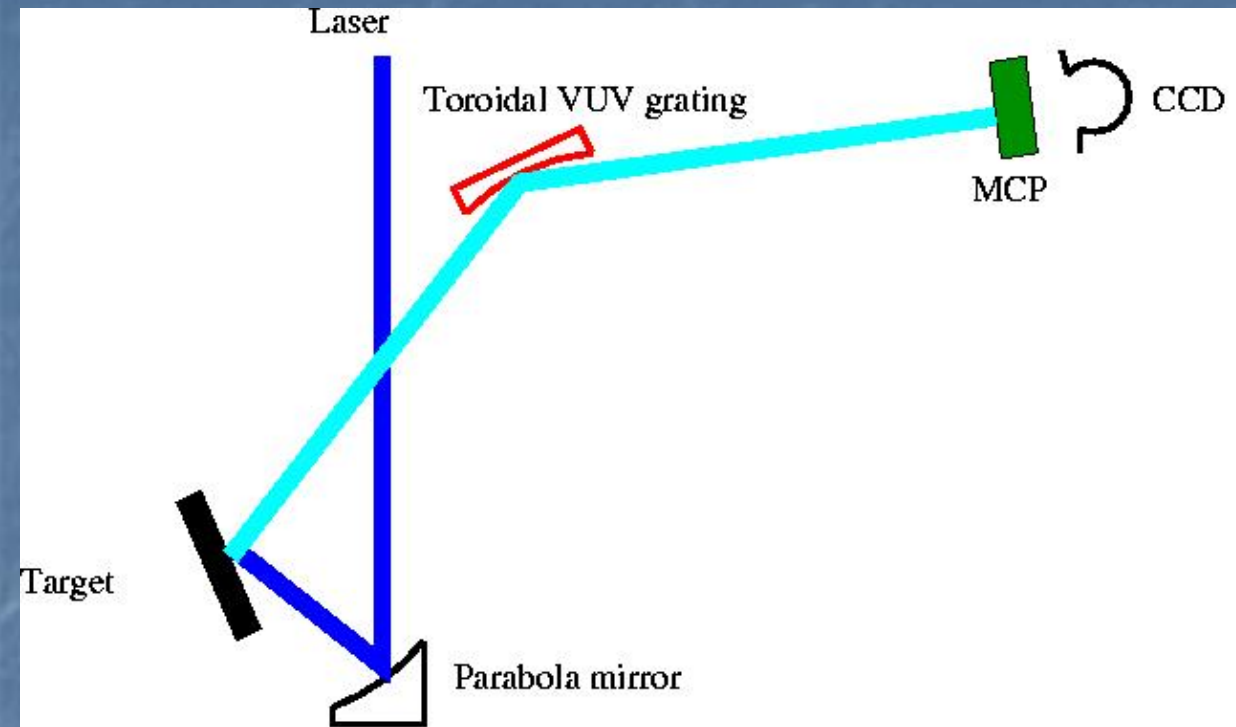


The short wavelength of the diffraction-limited beam allows focusing to a small spot by a Janos Inc. off-axis parabola.



The diameter of the focal spot is  $2\text{ }\mu\text{m}$ . Approximately 55% of the laser intensity was found inside this focal spot which corresponds to  $5 \cdot 10^{17}\text{ W/cm}^2$  intensity. The intensity of the ASE prepulse remained as low as  $10^7\text{ W/cm}^2$ .

# VUV spectroscopy



$3.4 \cdot 10^{17} \text{ W/cm}^2$  intensity  
on the target at  $45^\circ$   
angle of incidence.

Diagnostics:

- x-ray diodes
- VUV grating for  
10-150 nm.

Single-shot spectra on  
the MCP detector.

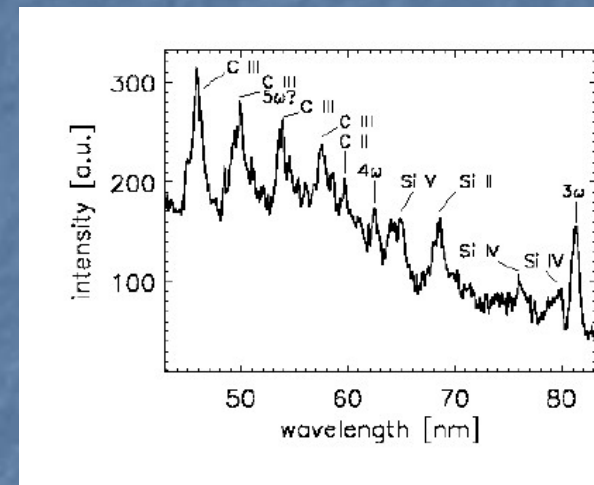
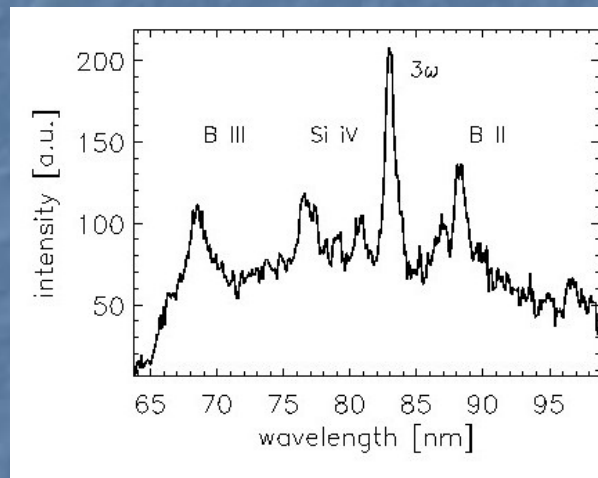
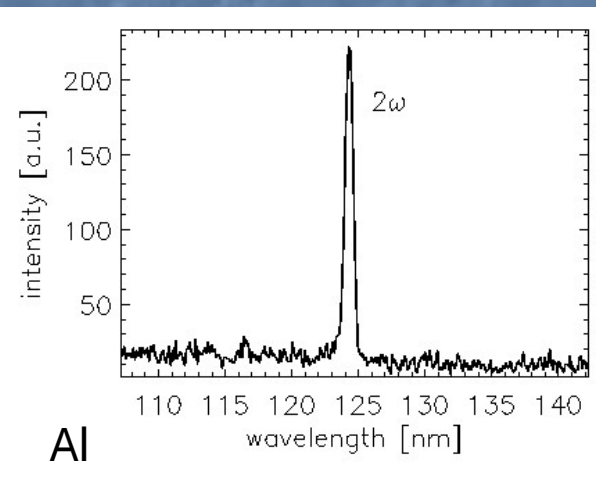
The main purpose of these experiments is the investigation of high-harmonics on the steep density gradient of the plasma generated by the ultrashort laser pulse. The mechanism of the high-harmonics generation gives important information about absorption mechanisms.

The low prepulse laser allows the heating of the solid by electron transport.  
preliminary for isochoric heating

# Harmonics to 62 nm wavelength



Second, third and **fourth harmonics** were observed in Al, B and C targets. The appearance of  $4\omega$  radiation at these intensities is crucial for clearing the generating mechanism, because even harmonics cannot be generated in a preplasma.

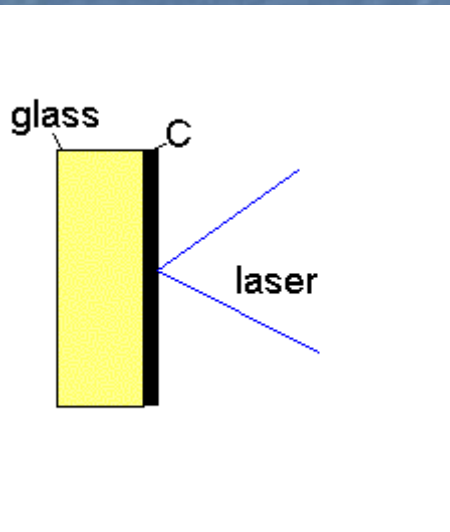


Similarly to previous experiments with lens-focusing harmonics were observed both for p- and s-polarized incidence of the laser beam. The study of the polarization of the harmonics is in progress. These results are probably caused by the ponderomotive force at the critical surface and the  $\mathbf{v} \times \mathbf{B}$  force in the evanescent wave in the overdense plasma even for the still nonrelativistic laser intensity.

# Preliminaries for the investigation of isochoric heating

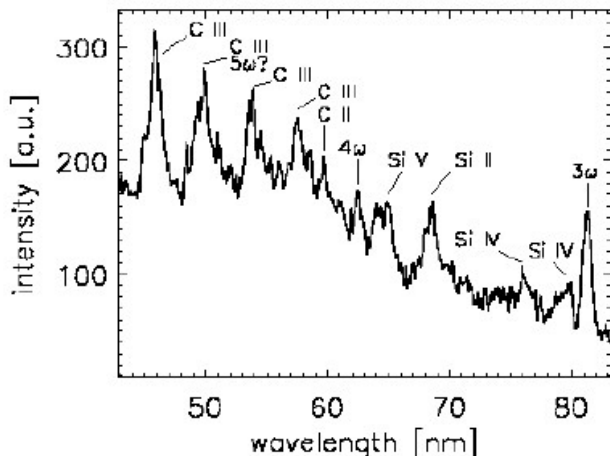
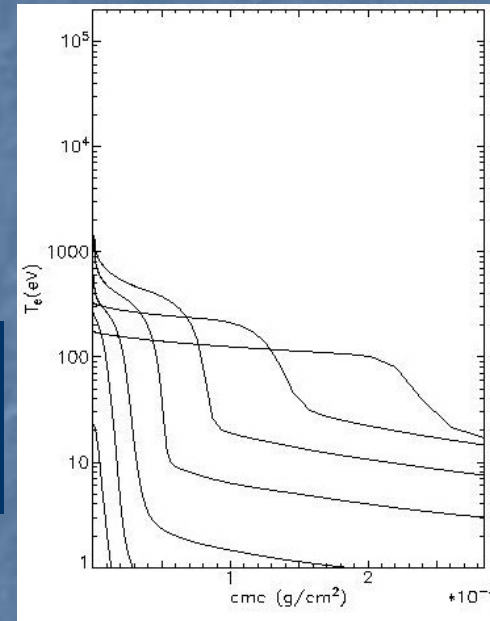


Fast ignition is based on isochoric heating by fast electrons



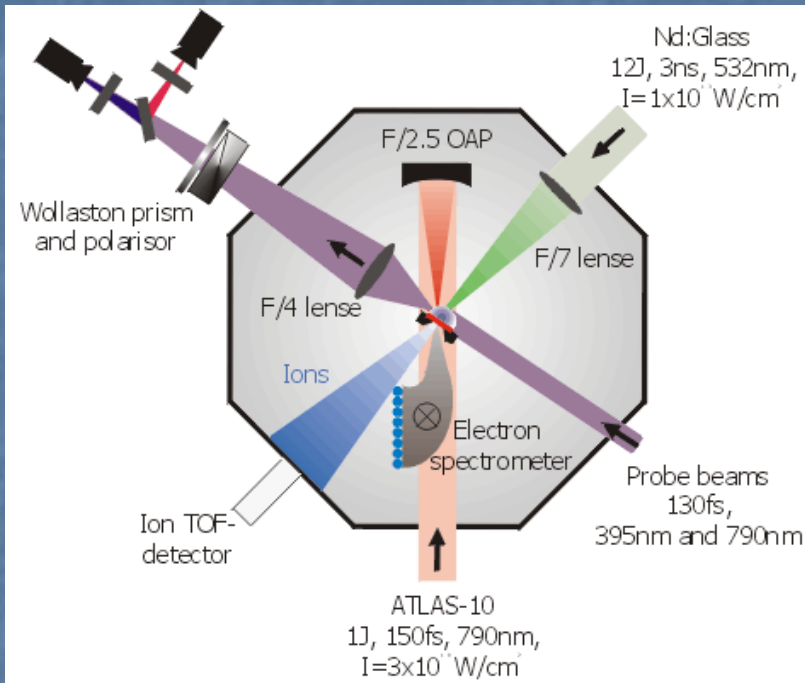
In the experiments target (C) layers of  $0.5 \mu\text{m}$  thickness were on glass plate.

According to MULTI-fs simulations of K. Eidmann temperatures of several 100 eV are expected in these depths.



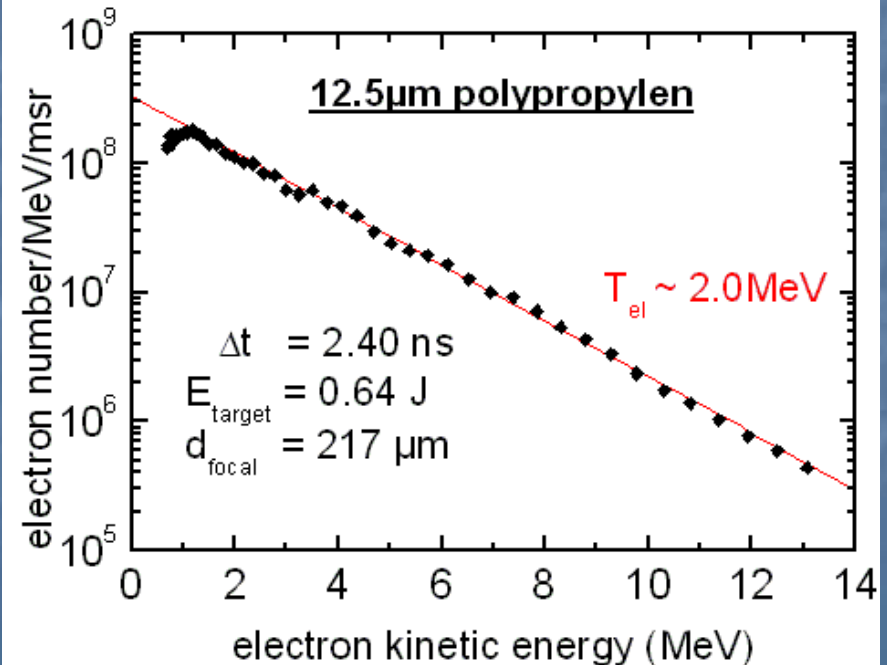
The observed Si V features from glass refer to temperatures of at least 50-150 eV, much higher than shock wave heating can give. The solid body is thus heated by the (fast) electrons from the corona. Experiments are in preparation with crystal spectrometer for higher x-ray energies.

# Collaboration in the MPQ. Fast electrons in preplasmas.

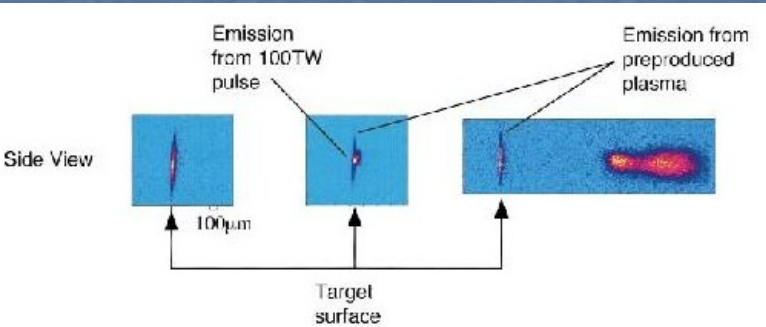


The experiments of M. Kaluza, G. Tsakiris and M. Santala showed fast electrons at the rear side of the target with a temperature of 2 MeV.

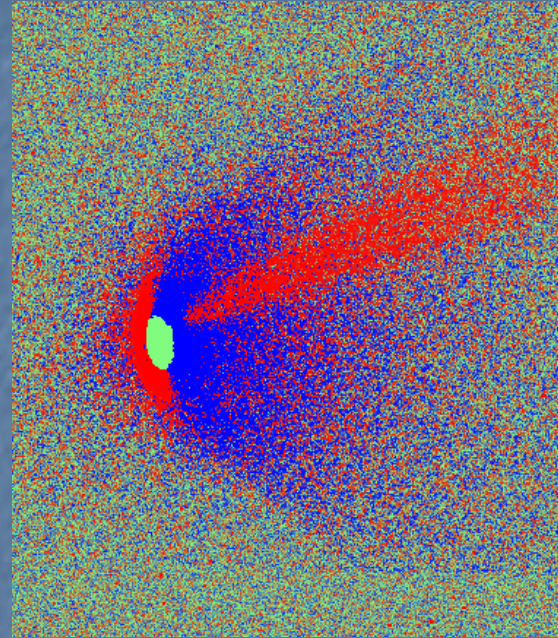
Our group investigated the preformed plasma at the front side with an x-ray pinhole camera.



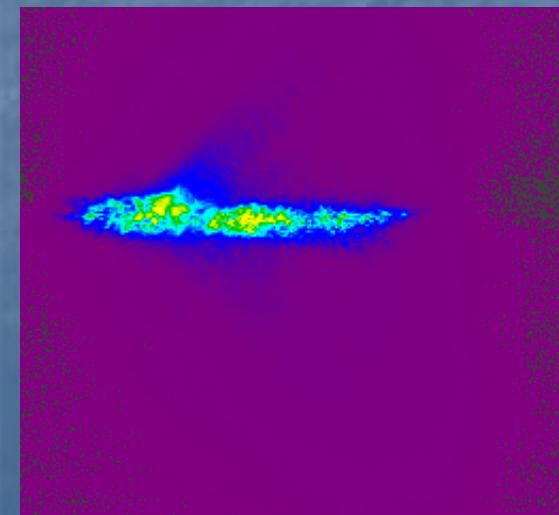
# Filamentary structure in the preplasma



Previous experiments of Tanaka et. al (2000) showed a filament in the x-ray pinhole image. They claimed that it is a result of self-focusing.

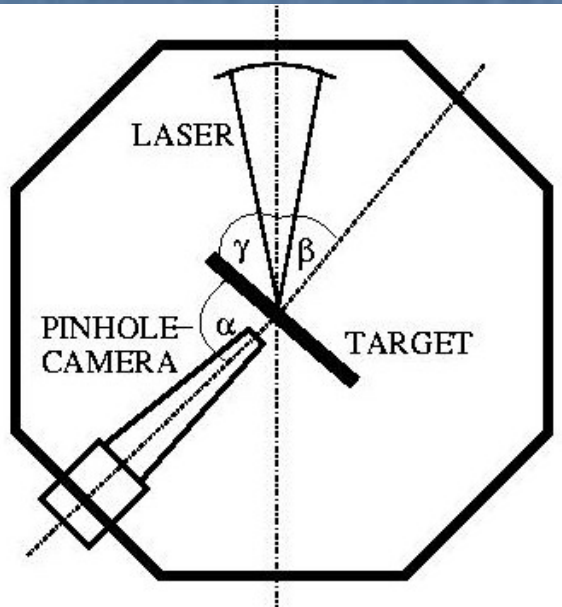


Our x-ray pinhole photograph for energies  $> 1\text{keV}$  shows intense radiation along the short laser pulse but no narrow filament.

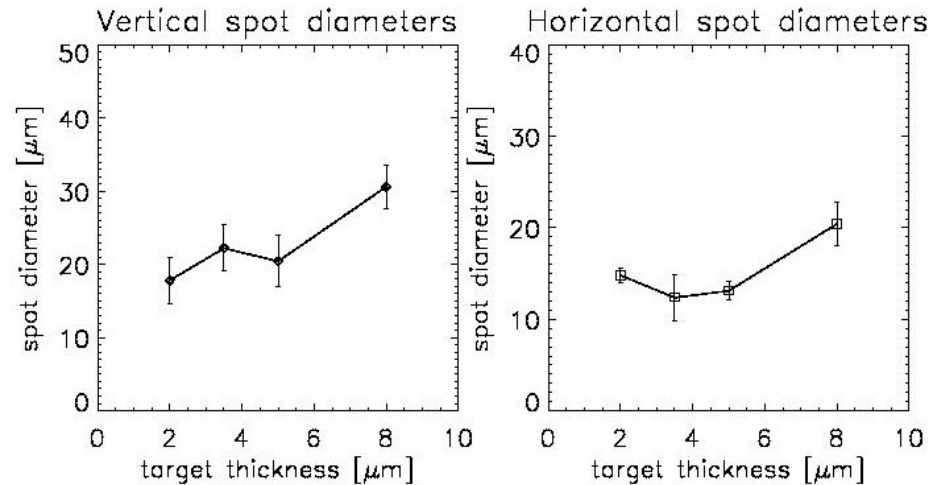


The scattered  $2\omega$  light shows filament, referring to self-focusing.

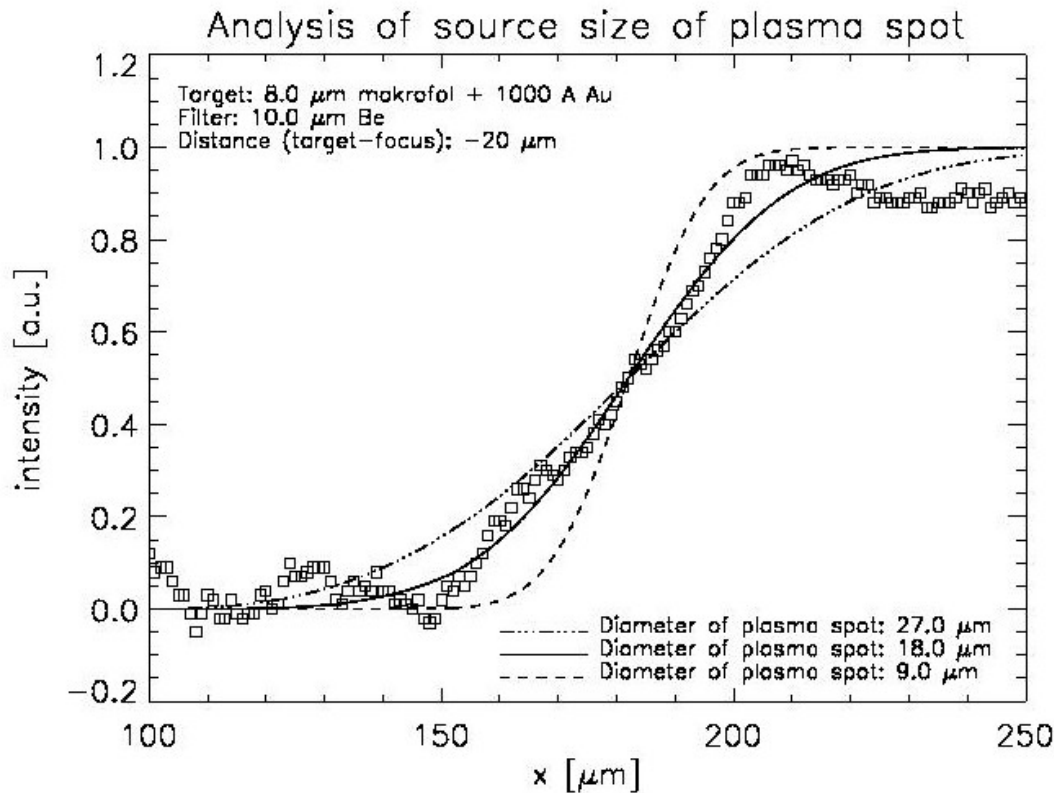
Although self-focusing is probably important in this case, the estimated plasma density of  $10^{19}\text{ cm}^{-3}$  is low, it is optically thin for the x rays generated in the filaments. Only the radiation caused by the ionizing effect of the main beam is seen.



X-ray pinhole camera for energies above 1keV viewed the rear side of the target when no prepulse was present.



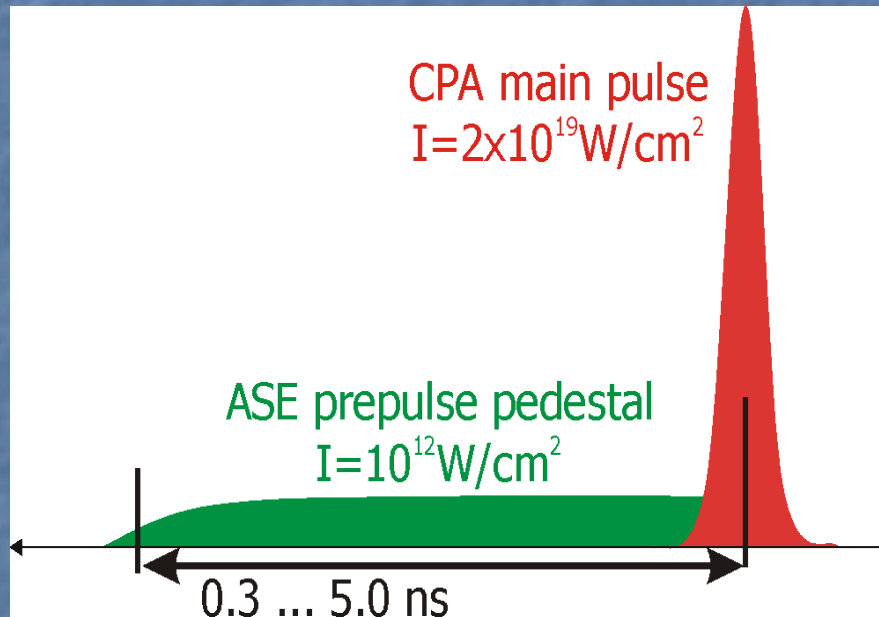
The results show no significant divergence of the electron beam in the target, the angle of divergence is less than  $12^\circ$  in agreement with V. Malka et al. (LULI) and M. Tatarakis et al. (RAL).



X-ray diffraction on a razor blade shows no significant divergence, too.  
 The measured spot diameter in this case is 18  $\mu\text{m}$ , too.

In the same times energetic proton beams were observed originating from the rear side of the target (M. Kaluza, G.D. Tsakiris). The experiments showed that in the previous strong prepulse-case the heat wave reaches the rear side, thus inhibiting the formation of the double layer, the source of proton acceleration.

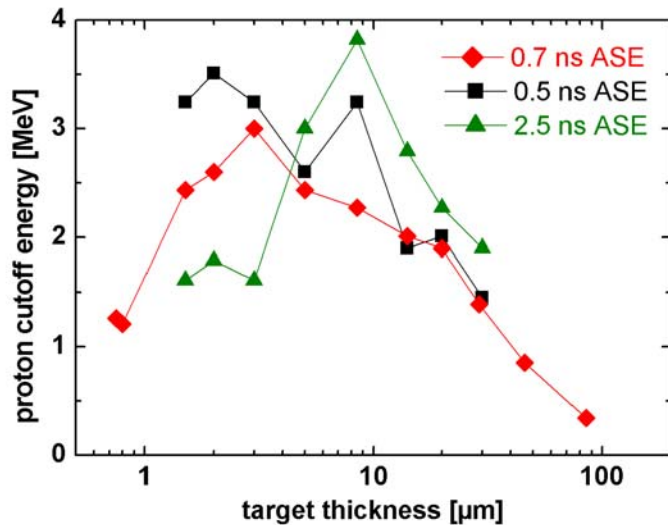
# Optimization proton energy for low ASE prepulses ( M. Kaluza et al., MPQ)



In the case of low intensity prepulse and sufficiently thick targets the heating does not reach the rear side, but in the preplasma a sufficient number of fast electrons are generated which can reach the rear side, there establishing the double layer for the proton acceleration. Varying the pulse duration of the prepulse and the thickness of the target allows one to optimize the energy of the proton beam.

# Cutoff-Energies for Different Thicknesses and Prepulse Durations

(from M. Kaluza)



- For longer prepulses maximal proton energy is achieved with thicker foils.
- If foil burns through, backside acceleration is suppressed.
- Clear indication, that high energy protons come from target backside!

# Trends in fast ignitor physics

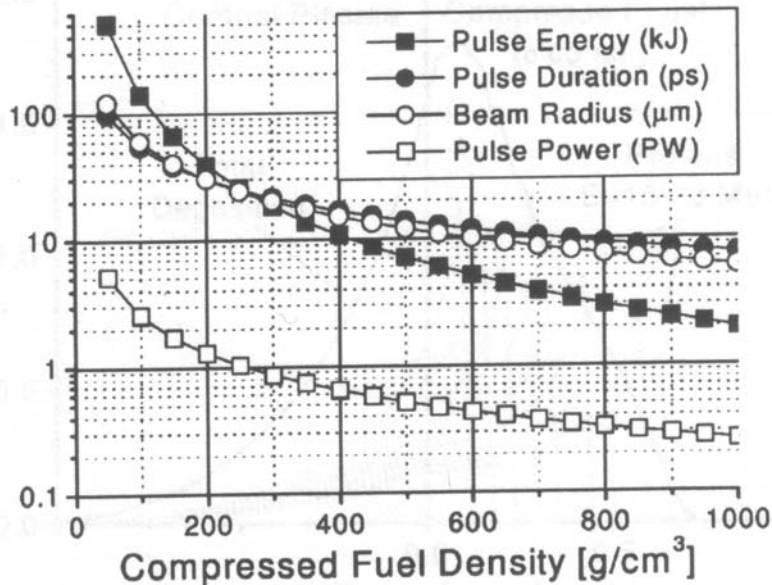


Reasons for fast ignitor:

- reduces required driver energy
- reduces symmetry requirements

The original scheme of Tabak et al. (1994)

- central spark ignition
- isobaric compression
- ~3kJ energy



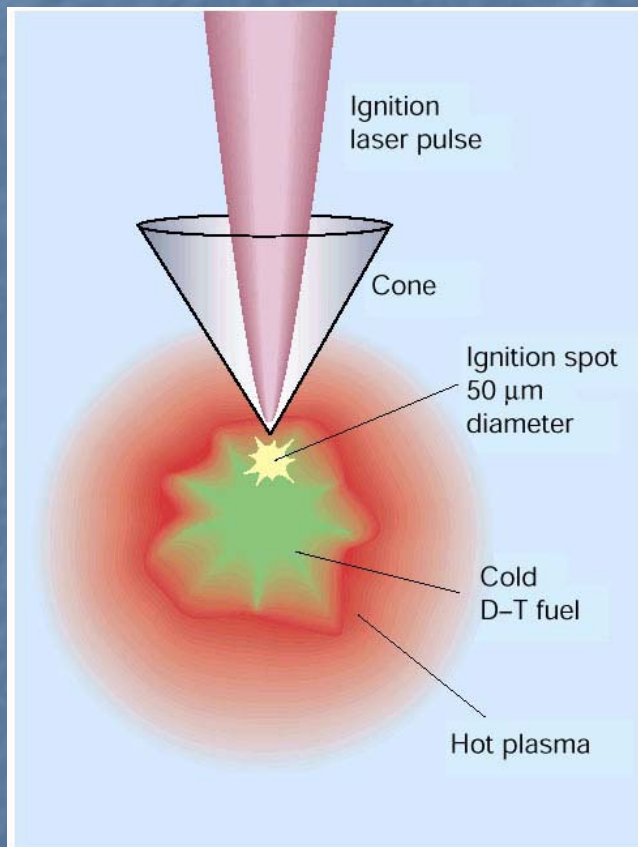
Fast ignition occurs in a uniform fuel:  
Isochoric scheme of S. Atzeni (1995, 1999)  
~ 2.4 times larger energy needed.

The motivation for studying isochoric heating

Parameter range for fast ignitor:  
Simulations of S. Atzeni, summarized by  
M. Roth et al., 2001

# Trends in fast ignitor physics

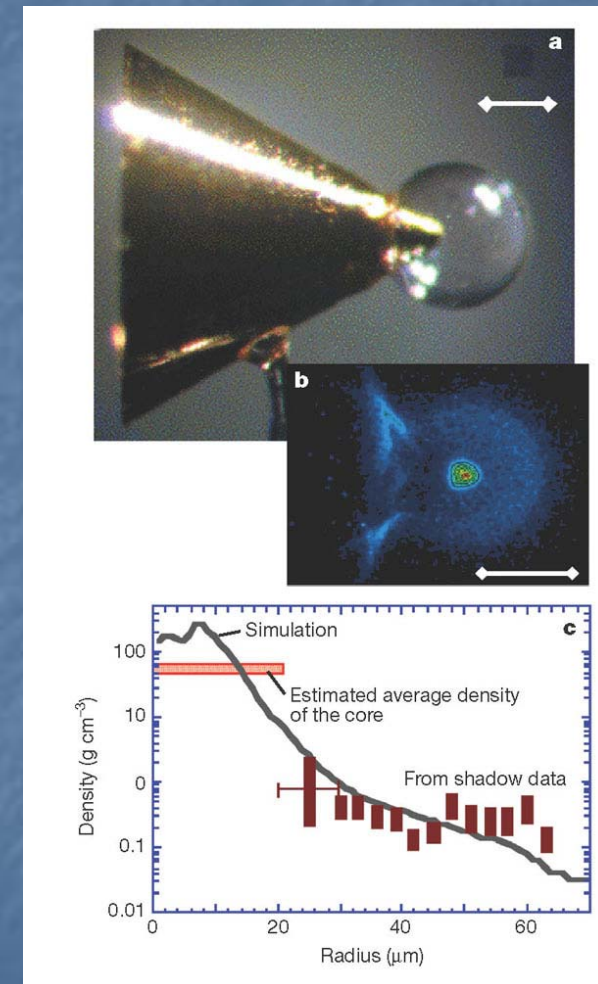
New results of the Fast-Ignitor Consortium (ILE, RAL)



The short pulse is guided with a gold cone to the precompressed DD fuel.

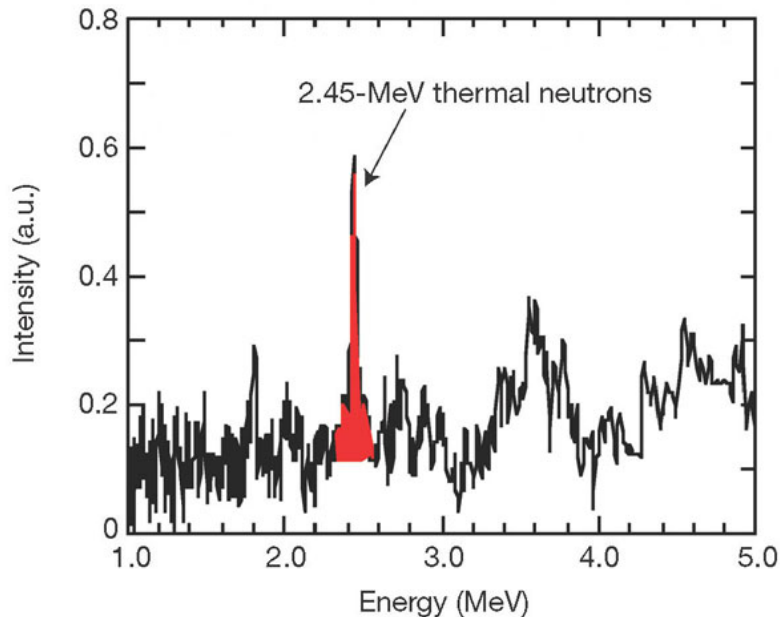
60 J  
0.06 pW  
1 ps

M. Key, Nature, 2001



R. Kodama et al., Nature 2001

# Trends in fast ignitor physics



Thermal neutrons were observed from the DD reaction.  
The 10x increase of neutron numbers corresponds to 1% temperature rise when using 0.1% of required ignitor energy.

R. Kodama et al., 2002: 0.5 pW laser energy resulted 3 orders of magnitude neutron number increase.

~2-fold temperature increase: 0.3-0.4  $\rightarrow$  0.8 keV.

0.6 ps pulse duration  $\ll$  measured 40 ps stagnation time.

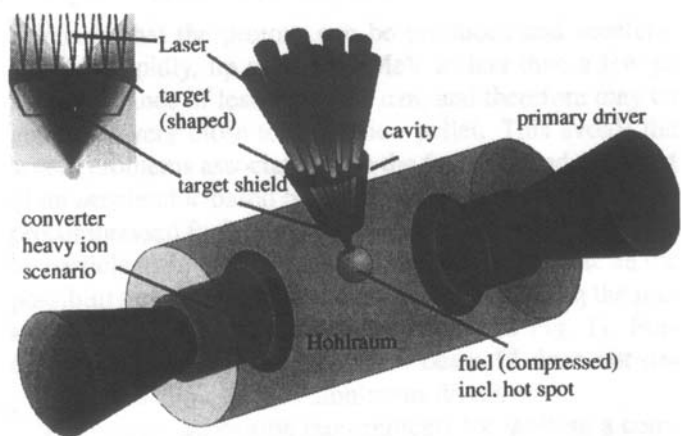
Consequence: Laser pulse duration can be increased, not the power.  
It can be scaled.

## Coronal ignition?

Traditional FI-scheme: Self-focused beam is guided to the overdense matter.  
Calculations of S. Hain and P. Mulser (2001):

- Bad news: hole boring does not work to high densities.
- Good news: Fast ignition is possible from the corona with diffusive transport.  
insensitive to precompression symmetry  
the reason why the Au cone works ?

## FI by proton beam? (M. Roth et al., 2001)



Basis: Highly directional proton beam was observed from the target rear side up to  $10^{13}$  protons of 6 MeV temperature.

Better focusing, source close to pellet  
but not directly coupled.

But even one more step, more indirect.



# Physical issues under investigation for fast ignitors



Fast electron transport in overdense matter

Simulations (M. Honda, J. Meyer-ter-Vehn, A. Pukhov, M. Tatarakis):

Small scale instabilities of electron beams.

Question: How it affects bulk propagation?

Experiments:

Propagation of fast electrons was measured to be nearly parallel.

G. Malka et al (LULI): 1 J, 30 fs,  $2 \cdot 10^{19}$  W/cm<sup>2</sup>.  $\theta < 15^\circ$ .

M. Tatarakis et al (RAL): 50 J, 1 ps,  $5 \cdot 10^{19}$  W/cm<sup>2</sup>.

Our results with MPQ: 1 J, 150 fs,  $10^{19}$  W/cm<sup>2</sup>.  $\theta < 12^\circ$ .

Parallel propagation of the fast electron beams open the possibility both for direct FI applications and for proton beam generation.

Question remains: How far can it be scaled up?

