INVESTIGATION OF THE HIGH-Z LASER-PRODUCED PLASMA WITH THE USE OF ION DIAGNOSTICS FOR OPTIMIZATION OF THE LASER INTERACTION WITH THE HOHLRAUM-TYPE TARGETS

The 3rd Progress Report on the IAEA Research Project No. 11535

Chief Scientific Investigator
Jerzy WOŁOWSKI
Institute of Plasma Physics and Laser Microfusion, Warsaw, Poland

OUTLINE

1. **Introduction.**
2. **Comparison of ion emission from high-Z plasmas generated by the high energy PALS laser at the fundamental and the 3rd harmonic frequencies.**
3. **Correlation of the x-ray and ion emissions from high-Z plasmas generated by the high energy PALS laser.**
4. **Fast ion generation in the plasma produced by a 1-ps high intensity laser pulse.**
5. **Summary.**

Research Coordination Meeting
4-7 November 2003, IAEA Headquarters, Vienna, Austria

1. INTRODUCTION

- Studies of ***high-Z plasma produced with high-power laser*** are directed towards the determination of ***physical processes*** in such a plasma (e.g., energy transformation and transport, X-ray generation, ionization and recombination, ion acceleration, nonthermal phenomena and others) as well as towards ***important applications*****:** ***optimisation of indirect laser fusion***, X-ray laser-plasma source and sources of multi-charged ions.

- The ***main objective of this project is application of ion diagnostic methods*** to investigate the physical properties of ***high-Z plasma generated by laser*** beams similar to the plasma produced inside the Hohlraum.

- In this project we would like to determine the characteristics of this plasma in dependence on ***laser pulse parameters*** (intensity, pulse duration, wavelengths, energy), illumination geometry (focus position, target tilt angle) and ***target material***.

- Combined measurements of high-Z laser-produced plasma using ***different diagnostic methods*** are better for quantitative ***analysis of the processes*** essential for optimal indirect implosion of thermonuclear capsule.

1. INTRODUCTION (continued)

- The experiments described here ***were continuation of the previous investigations*** of specific features of ***high-Z plasma*** generated by the high-power performed within this project.

- These studies were carried out at the ***IPPLM in Warsaw*** with use of the IPPLM CPA Nd:glass laser generating 1-ps or 0.5-ns pulses at λ = 1.05 μm and at the ***PALS Research Centre in Prague*** with the use of the iodine PALS laser system with output energy up to 750 J at the fundamental wavelengths (1.315 μm) or up to 250 J at the 3^{rd} harmonic (0.438 μm) in a 0.4 ns pulse.

- Investigations are carried out by means of ***diagnostic devices used in the preliminary experiment*** (i.e. ion collectors, a cylindrical electrostatic ion energy analyzer and X-ray detectors) and additionally with the use of ***modernised ion collectors, improved X-ray detectors and nuclear track detectors for fast ions***.

- The investigations performed at the PALS Research Centre in Prague were carried out within ***multilateral co-operation*** with the Institute of Physics and Institute of Plasma Physics ASCR in Prague and with scientists from several other institutes.

2. Comparison of ion emission from high-Z plasmas generated by a high energy PALS laser at the fundamental and at the 3rd harmonic frequencies

2. Comparison of ion emission from high-Z plasmas generated by a high energy PALS laser at the fundamental and at the 3rd harmonic frequencies

INTRODUCTION

The ion emission from laser-produced plasmas is a well known phenomenon which has been studied since the early 1960s.

For a long time the interest in studies of the ion emission has been stimulated by the importance of this phenomenon for ***laser-driven inertial confinement fusion***.
In more recent works, however, some ***useful aspects*** of ion emission from laser-produced plasma have been emphasised.

In particular, the possibility of applying laser-driven ion sources (LIS) in ***accelerator technology and for modifying material properties*** through ion implantation has been suggested and investigated.

The energy of an intense laser pulse interacting with a target ***is not completely transferred to the plasma in the collisional (thermal) processes.***

In particular, as a result of the ***long-wavelength laser-plasma interaction***, the nonthermal coupling processes transfer a part of laser energy into the energy of ***hot electrons***.

The ***fast ions*** appear as a result of ion acceleration in the ***electrostatic field created by the electrons***.

2. Comparison of ion emission from high-Z plasmas generated by a high energy PALS laser at the fundamental and at the 3rd harmonic frequencies

INTRODUCTION (continued)

The efficiency of the ***hot electron production decreases*** with the ***decreasing of the laser wavelength***.

There are also several ***nonlinear phenomena*** (e.g. filamentation and self-focusing of the high intensity laser beam, ponderomotive forces) ***weakly dependent on the laser wavelength***, which can lead to the fast ion production in the case of the ***short-wavelength laser-plasma interaction***.

It is interesting ***to compare the characteristics of fast ions accelerated*** in plasmas produced by the intense long- and short-wavelength laser radiation in similar experimental conditions.

2. Comparison of ion emission from high-Z plasmas generated by a high energy PALS laser at the fundamental and at the 3rd harmonic frequencies

EXPERIMENTAL ARRANGEMENT

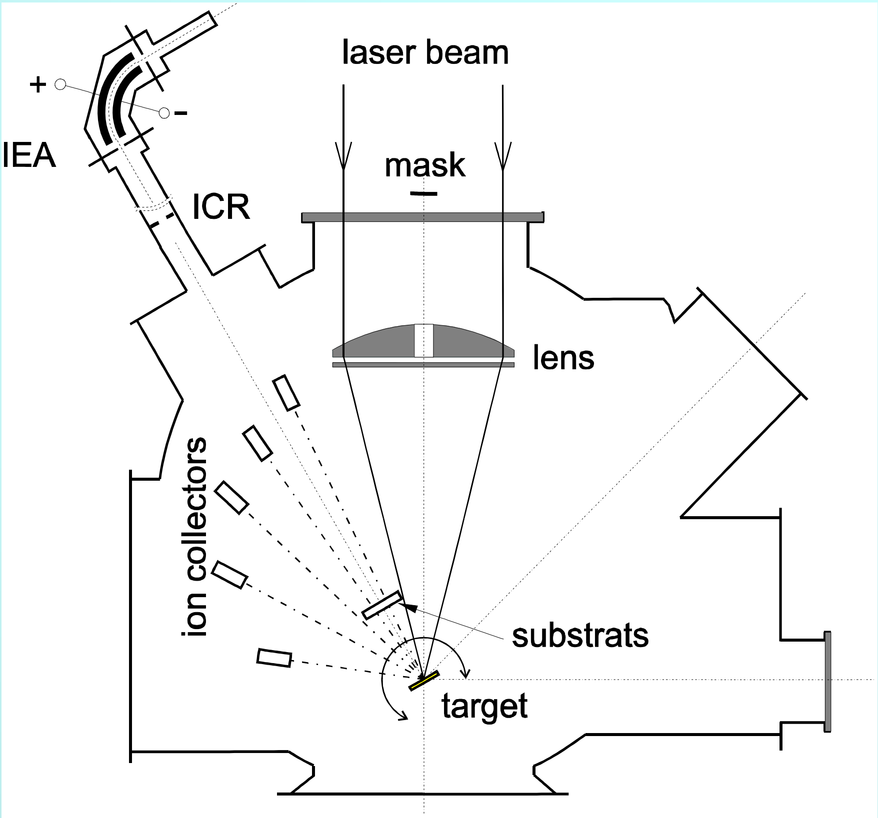
The PALS laser parameters:

- energy of ***0.4-ns*** pulse at wavelength of ***1315 nm (1ω_0): < 750 J*** at wavelength of ***438 nm (3 ω_0): < 250 J***
- power density – up to ***10^{16} W/cm^2*** (at spot diameter of ***~70 μm.***

* The laser beam was focused onto a slab targets (Cu, Ag and Ta) by means of an aspherical lens at an ***angle of 30º*** with respect to the target normal.

* Five ion collectors ***were located inside the vacuum chamber, at angles from 4º to 52º with respect to the target normal and at distances of 30–60 cm from the target surface.***

* The ion energy analyzer (IEA) ***and a "ring" ion collector (ICR) were placed far from the target perpendicularly to the target surface.***



IEA – ion energy analyzer, ICR – "ring" ion collector

* Additionally, the ***solid-state nuclear track detectors*** (PM-355) uncovered as well as ***masked with 0.75, 1.5 and 4 μm Al-foils*** were also used for measurements of ***high-energy ions.***

2. Comparison of ion emission from high-Z plasmas generated by a high energy PALS laser at the fundamental and at the 3rd harmonic frequencies

ELECTROSTATIC ION ENERGY ANALYZER (IEA)

The IEA gives a possibility to ***distinguish all ionization states and energy of ions*** at a long distance from the target. Only ions with particular values of m_i/z can pass through the IEA and reach the detector (WEM).

From the equation of motion:

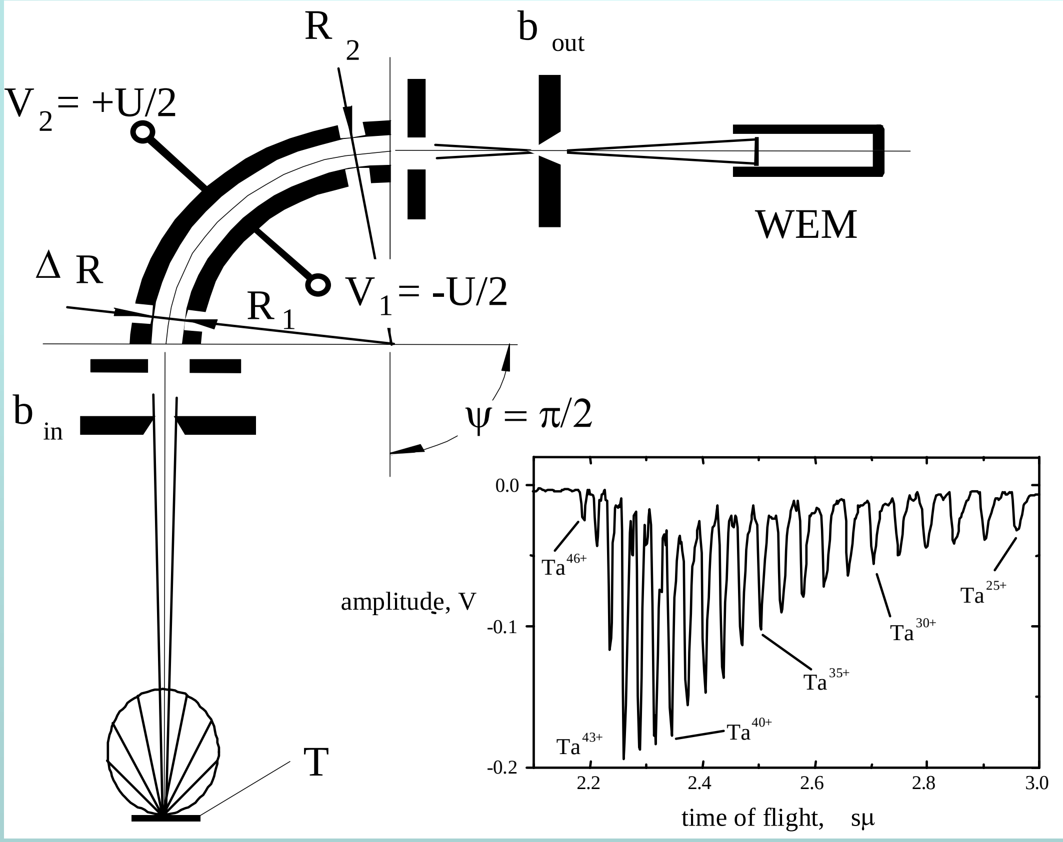
$$E_i/z = \kappa e U$$

and time-of-flight of ions on the path L_{IEA} from the target to the detector:

$$t = L_{IEA}(m_i/2E_i)^{1/2} = L_{IEA}[m_i/(2ez\kappa U)]^{1/2}$$

where: E_i – kinetic energy,
m_i - ion mass,
z - charge state,
κ - geometric factor,
e - elementary charge,
U - deflection voltage

one can determine the ***essential parameters of particular ion species***.

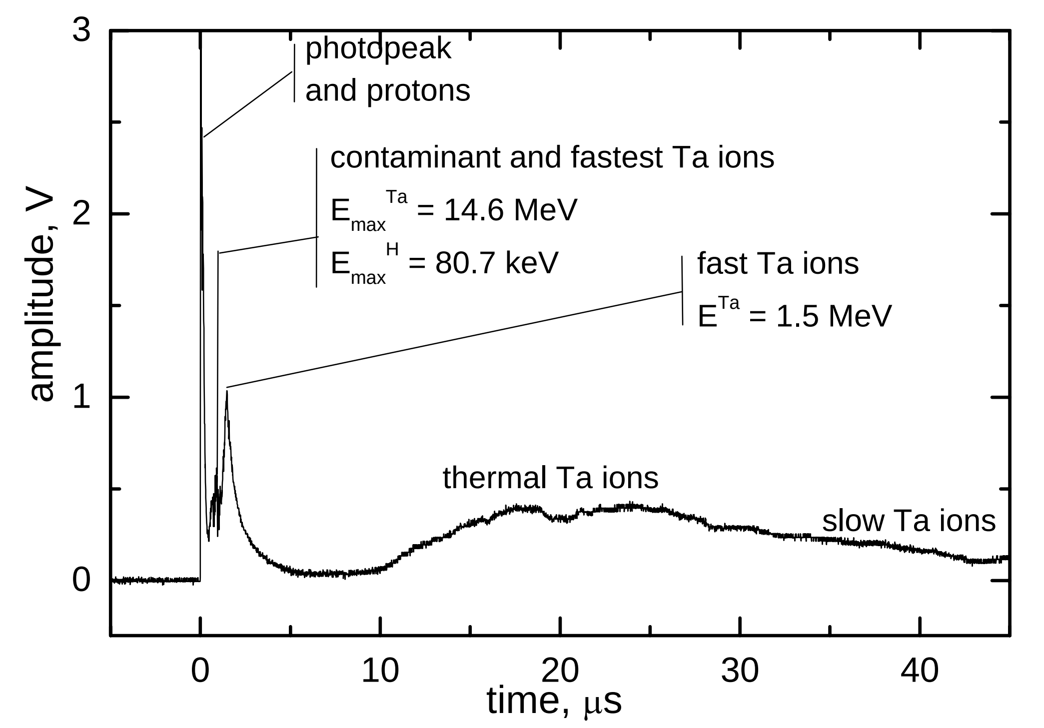


2. Comparison of ion emission from high-Z plasmas generated by a high energy PALS laser at the fundamental and at the 3rd harmonic frequencies

AN EXAMPLE OF ION COLLECTOR SIGNAL OF Ta PLASMA

Ion collector signal shows the occurrence of ***different group of ions*** reaching the IC.

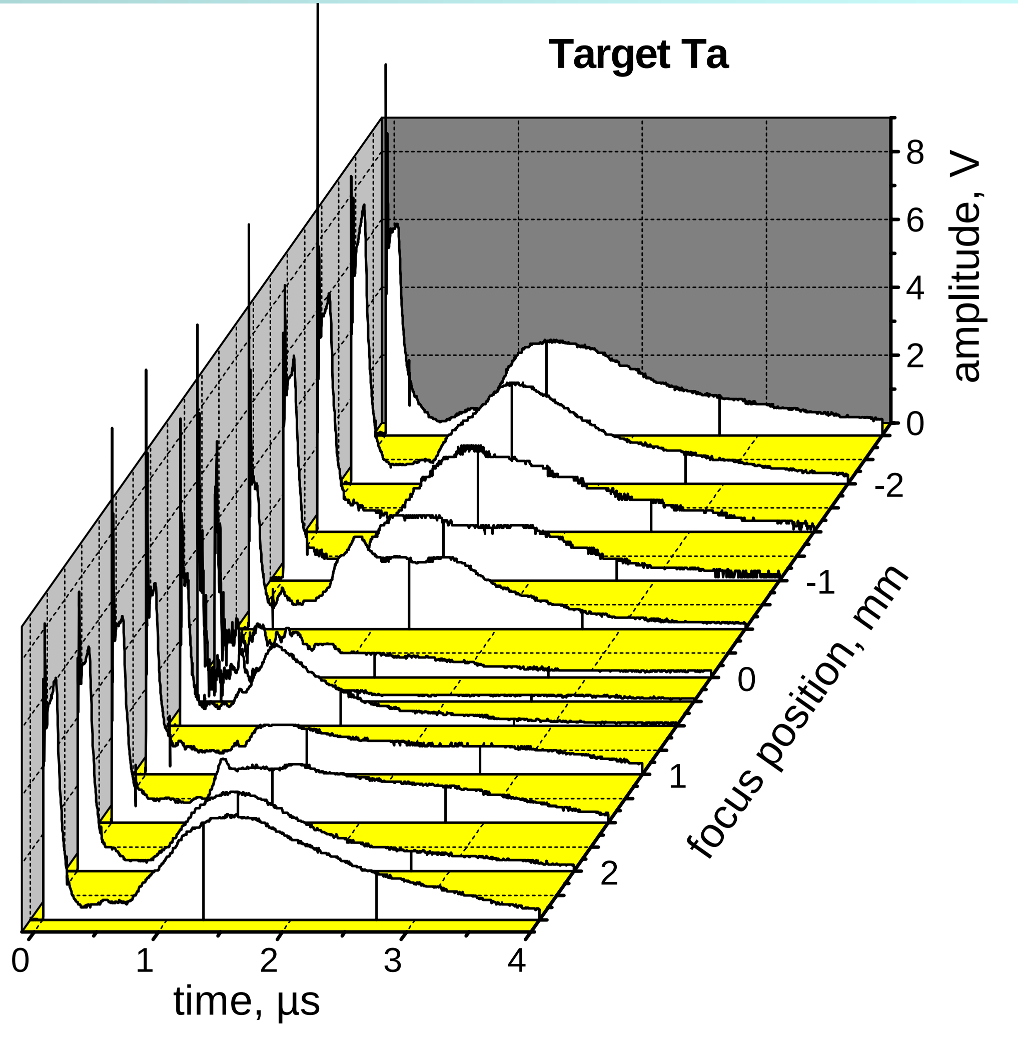
- The first maximum represents photopeak and ***contaminant ions*** (mainly protons).
- The second ion group consists of ***fast, high-Z ions***.
- The third one corresponds to ***thermal high-Z ions***.
- The forth one consists of ***slow high-Z ions*** generated indirectly around the laser focus spot by the X-rays emitted from the hot plasma.



The IC signal was recorded at the distance of 182.2 cm from the target along the target normal (3ω_0, laser energy =200 J

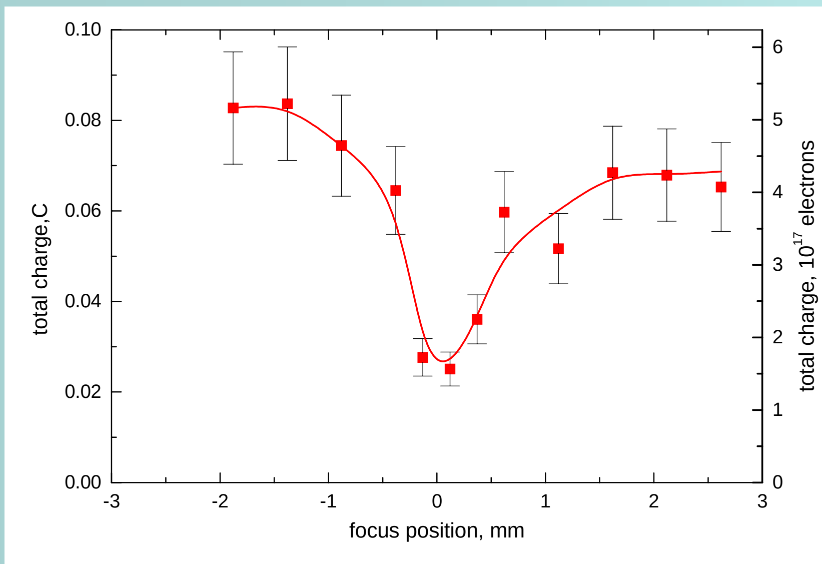
2. Comparison of ion emission from high-Z plasmas generated by a high energy PALS laser at the fundamental and at the 3rd harmonic frequencies

ION COLLECTOR SIGNALS IN THE FUNCTION OF THE ION ARRIVING TIME AND IN THE FUNCTION OF TARGET DISPLACEMENTS

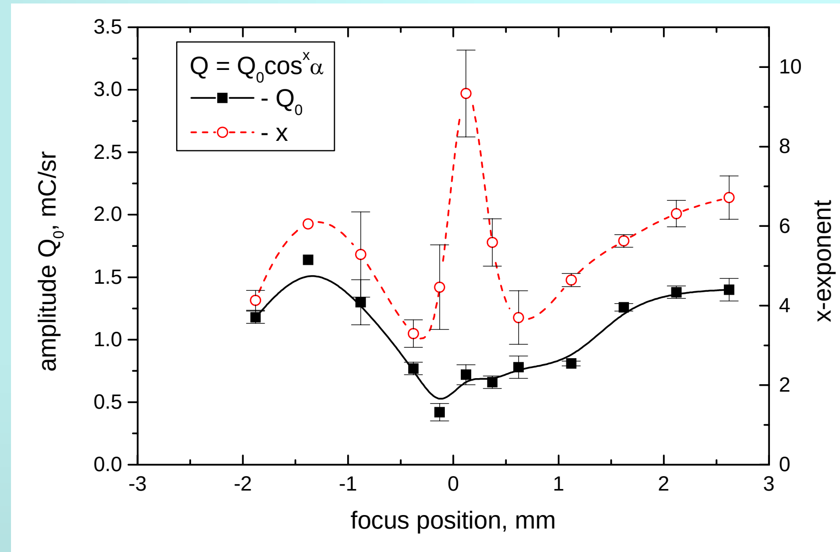


2. Comparison of ion emission from high-Z plasmas generated by a high energy PALS laser at the fundamental and at the 3rd harmonic frequencies

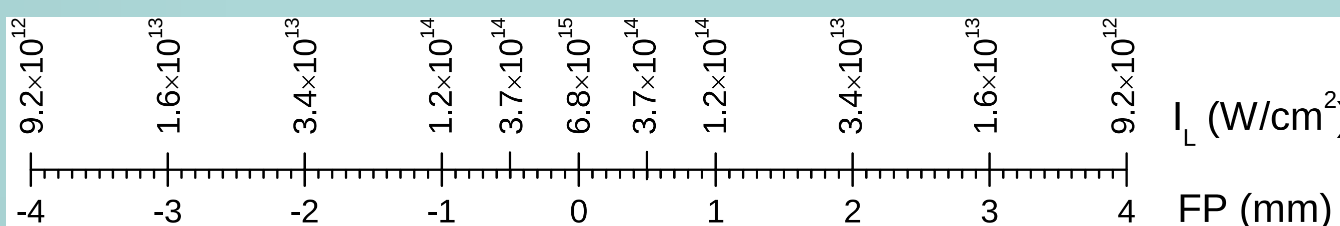
DEPENDENCE OF Ag ION STREAM PARAMETERS ON A FOCUS POSITION AT $1\omega_0$



The total charge carried by ions as a function of focus position.



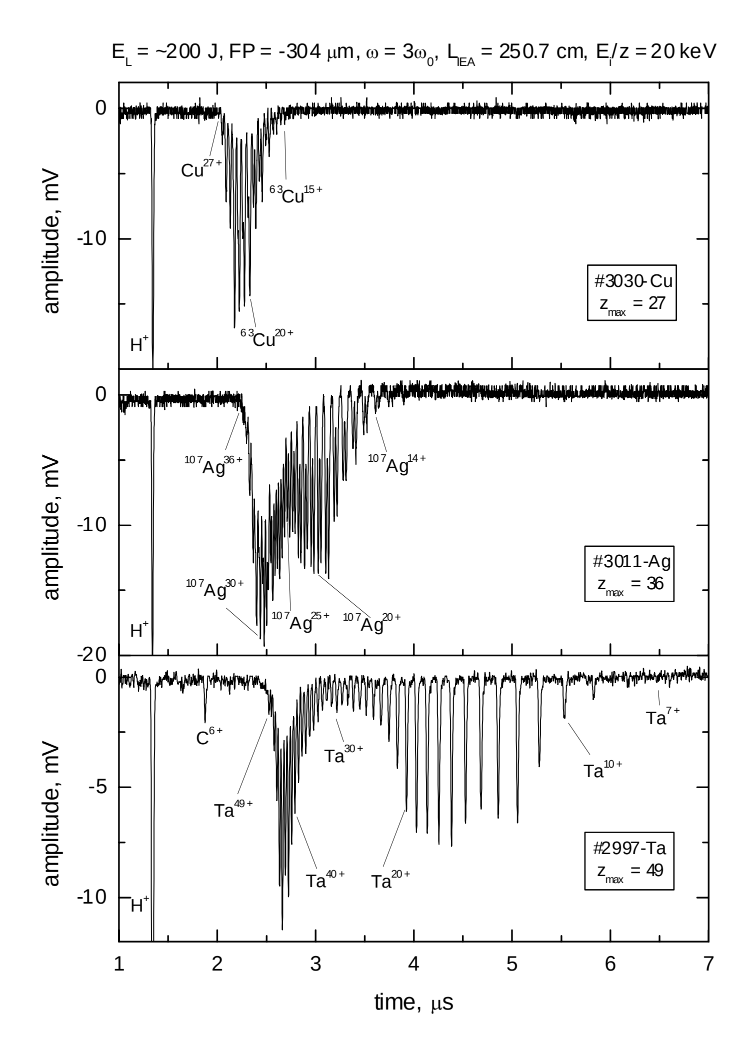
The amplitude of Q_0 and ***x-exponent*** of ion angular distributions roughly described by $Q = Q_0 \cos^x(\alpha)$



The laser intensity (I_L) in the dependence on the focus position (FP).

2. Comparison of ion emission from high-Z plasmas generated by a high energy PALS laser at the fundamental and at the 3rd harmonic frequencies

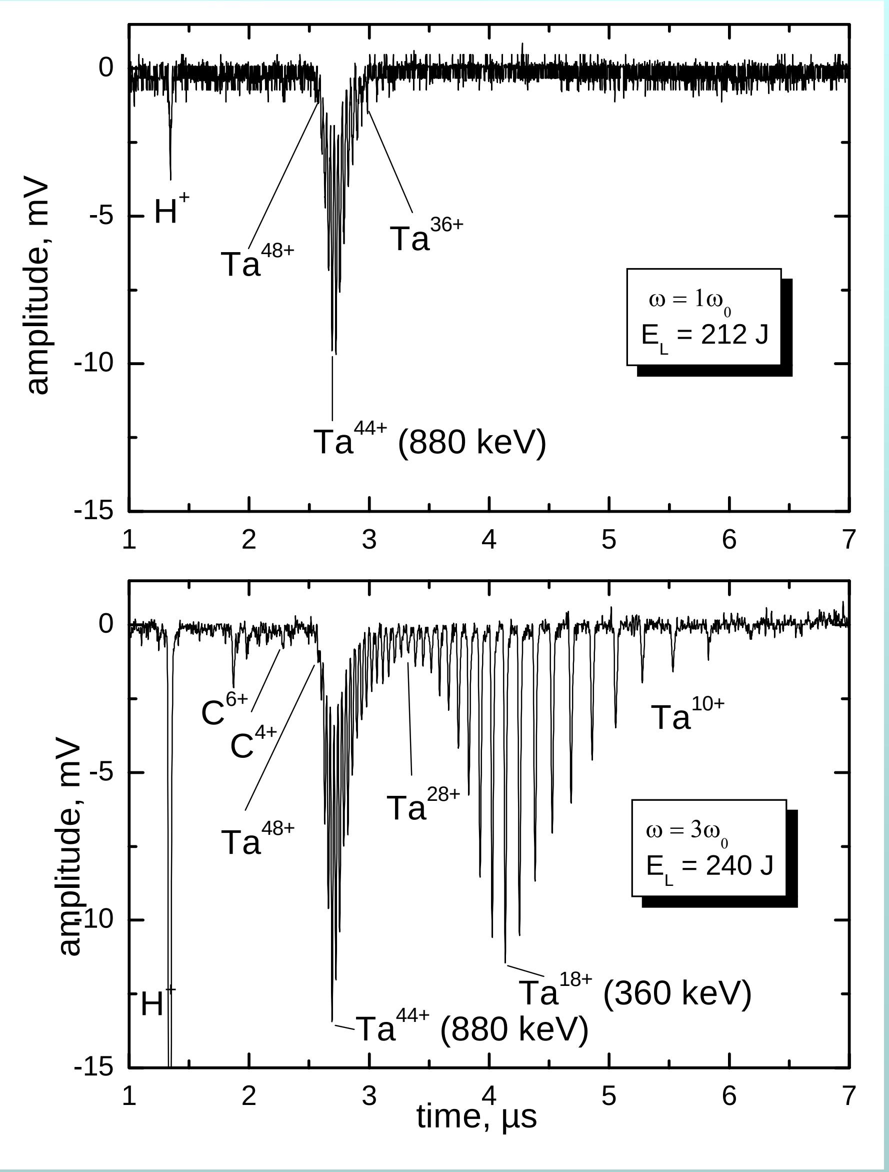
EXAMPLES OF THE IEA SPECTRA OF Cu, Ag AND Ta LASER-GENERATED IONS RECORDED AT THE SAME EXPERIMENTAL CONDITIONS



2. Comparison of ion emission from high-Z plasmas generated by a high energy PALS laser at the fundamental and at the 3rd harmonic frequencies

IEA SPECTRA OF Ta IONS RECORDED AT 1315 nm AND 438 nm

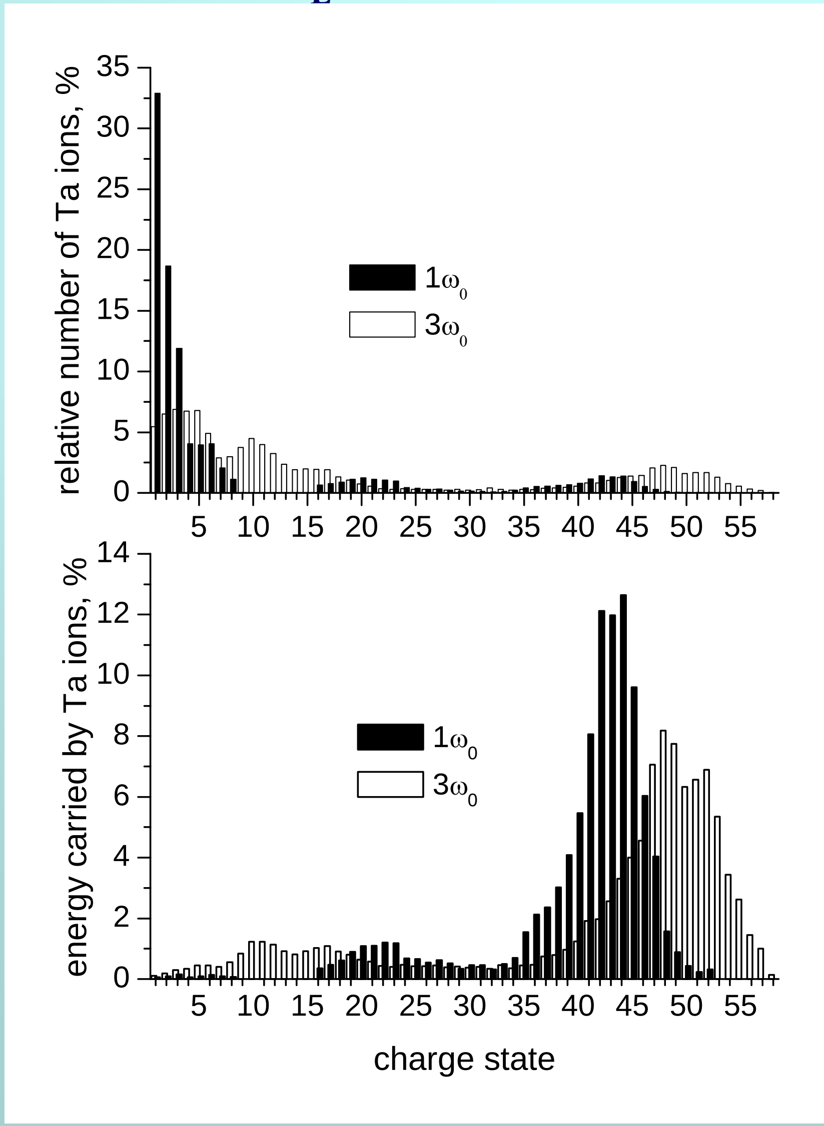
- The group of ***fast highly charged Ta ions*** is represented by a part of the spectrum recorded from ***~ 2.4 to ~3.5 μs***.
- The shapes of the IEA spectra for both wavelengths are different.
- In particular, the stream of ***medium-charged and medium energy ions*** was much more intense in the case of visible radiation than at infrared laser radiation.



2. Comparison of ion emission from high-Z plasmas generated by a high energy PALS laser at the fundamental and at the 3rd harmonic frequencies

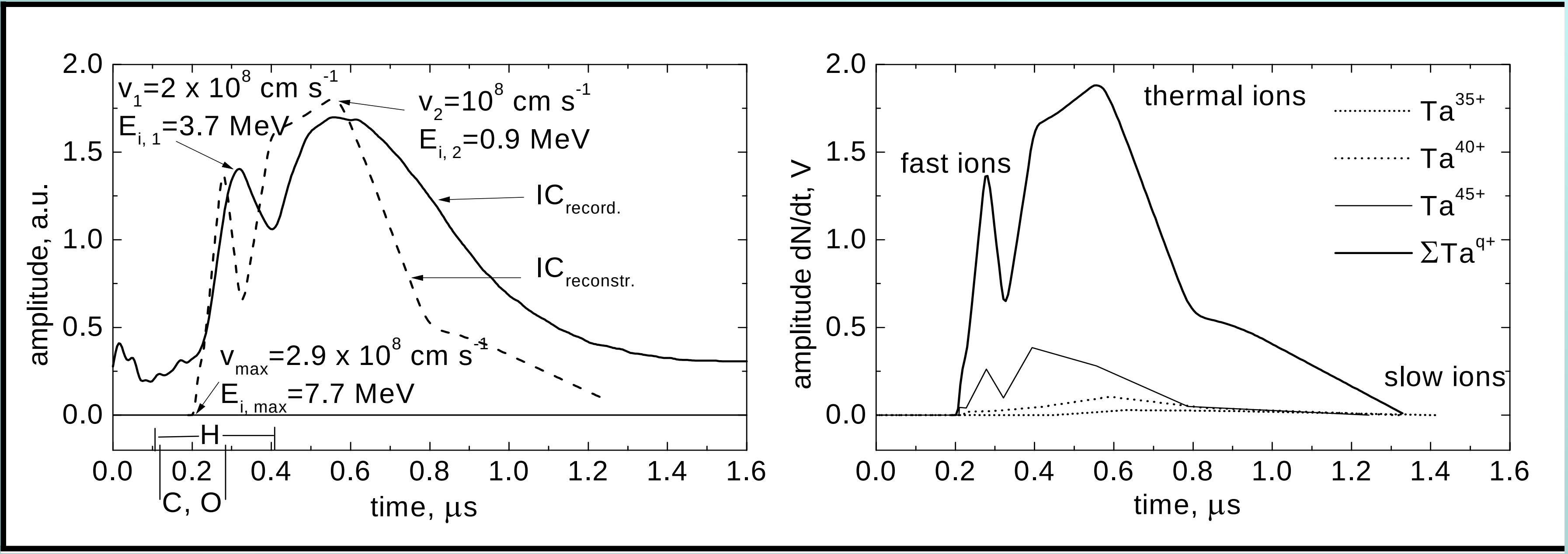
DISTRIBUTION OF Ta ION ENERGY (TOP) AND ABUNDANCE (BOTTOM) WITH CHARGE (E_L~225±15 J).

- The group of ***highly charged (z > 35) Ta ions***, which carried a significant part of the total energy of all the ions is shown in the diagram.
- In the case of ***1315 nm*** radiation this group is ***more significant*** than for 438 nm light.



2. Comparison of ion emission from high-Z plasmas generated by a high energy PALS laser at the fundamental and at the 3rd harmonic frequencies

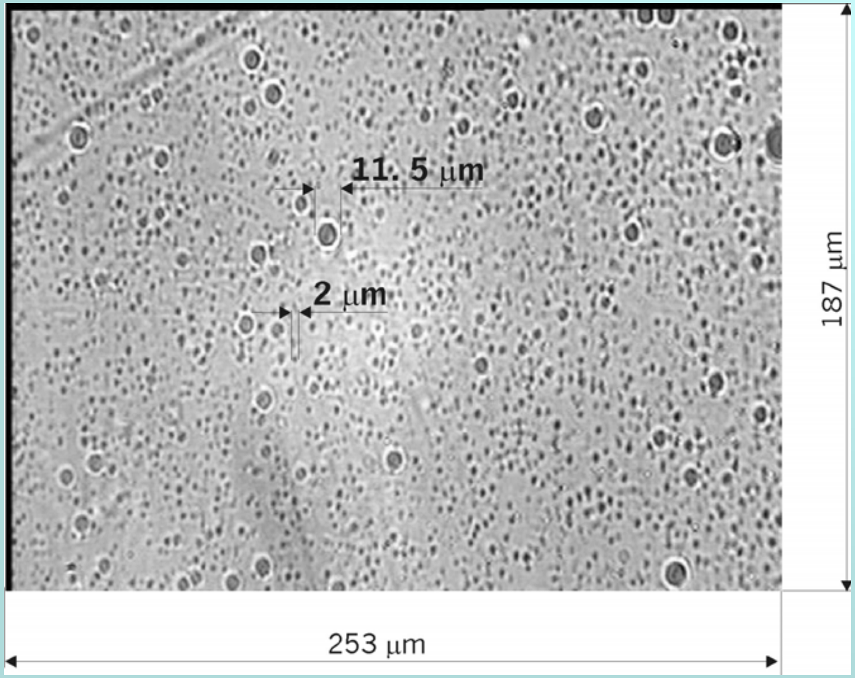
ION COLLECTOR SIGNALS RECORDED AND RECONSTRUCTED ON THE BASIS OF THE *IEA* MEASUREMENTS AT $1\omega_0$



$E_{i,1}$, $E_{i,2}$, - fast and thermal ion energies, respectively,
v_1, v_2 - velocities of fast and thermal ions, respectively.

2. Comparison of ion emission from high-Z plasmas generated by a high energy PALS laser at the fundamental and at the 3rd harmonic frequencies

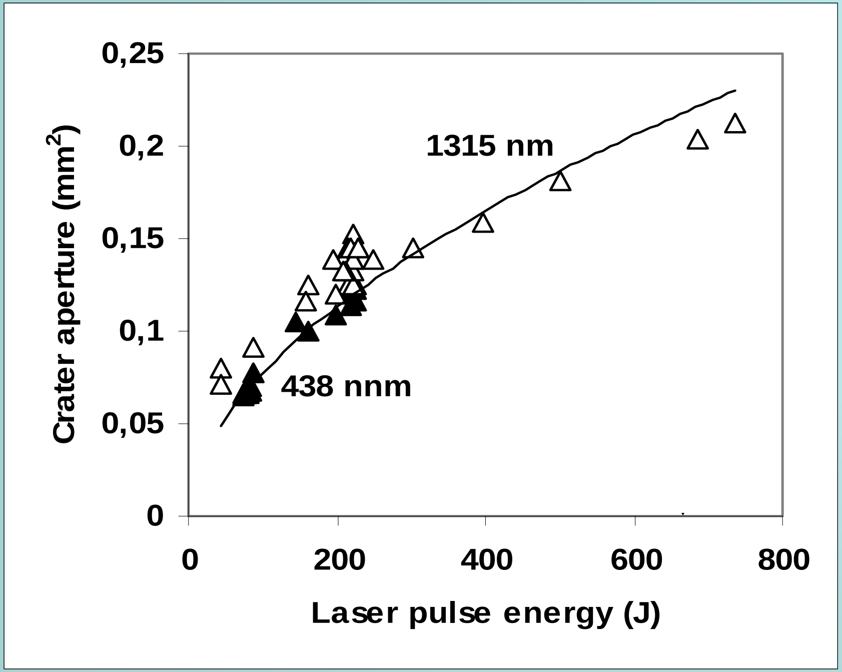
MEASUREMENTS OF FAST IONS WITH THE USE OF SOLID STATE TRACK DETECTORS

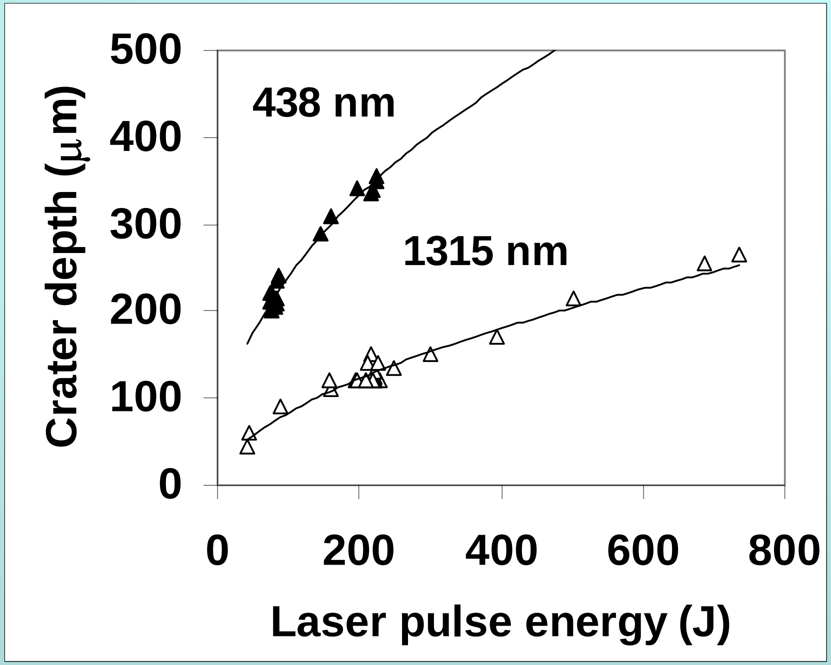


- Ion tracks were recorded on the PM-355 detector covered with a ***4 μm Al-foil filter*** (three laser shots at $E_L \approx 80$ J).
- The ***tracks of larger diameter*** were inducted by ***energetic (>22 MeV) Ta ions***. The ***small diameter tracks*** were produced by ***protons of energy >0.5 MeV***.
- Track densities of ***>10^7 tracks/cm^2*** for Ta-ions were observed.
- The Ta ion energies corresponded well to the maximum Ta ion energies determined from the ion collectors signals.

2. Comparison of ion emission from high-Z plasmas generated by a high energy PALS laser at the fundamental and at the 3rd harmonic frequencies

DIMENSIONS OF CRATERS PRODUCED IN THE TARGETS A FUNCTION OF THE LASER PULSE ENERGY

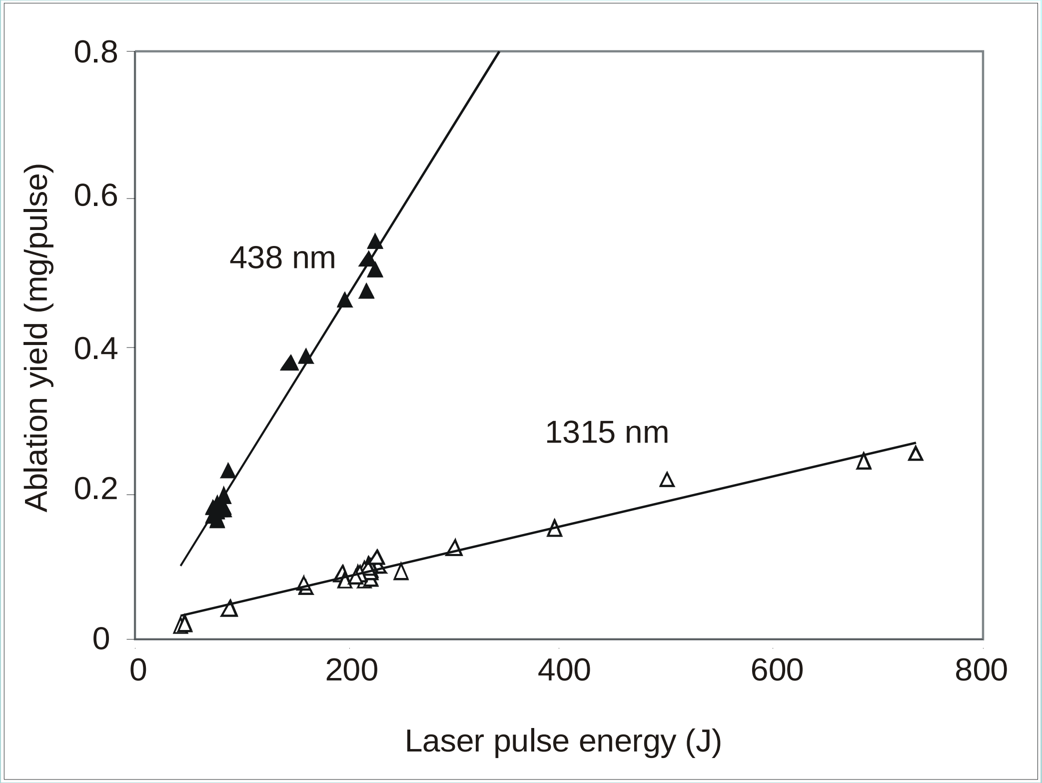




- The craters produced were analyzed by a ***scanning electron microscope and by a high sensitivity profiler system***.
- The ***crater diameters increase*** with the laser pulse energy ***similarly*** for the both laser wavelengths.
- But the ***crater depths increases*** with energy ***faster for visible laser radiation*** in comparison with the depths of the craters produced by the infrared laser.

2. Comparison of ion emission from high-Z plasmas generated by a high energy PALS laser at the fundamental and at the 3rd harmonic frequencies

ABLATION YIELD OF A TARGET MATERIAL AS A RESULT OF LASER-TARGET INTERACTION



- ***High ablation yields (0.1-0.6 mg per pulse)*** were measured as a function of the laser pulse energy at both the wavelengths.
- At ***438 nm*** significantly ***higher ablation rates*** were observed.

3. Correlation of the x-ray and ion emissions from high-Z plasmas generated by a high energy PALS laser system

3. Correlation of the x-ray and ion emissions from high-Z plasmas generated by a high energy PALS laser system

INTRODUCTION

Ion and x-ray emission from laser plasmas often needs to be modified ***to fit the specific applications*.**

The ***changing of the focusing condition*** of the laser beam is the easiest method of modification of the ***characteristics of ion and x-ray beams*.**

It is difficult to keep the same level of focusing in the broad range of laser energy because the convergence of the laser beam may change to a great extend.

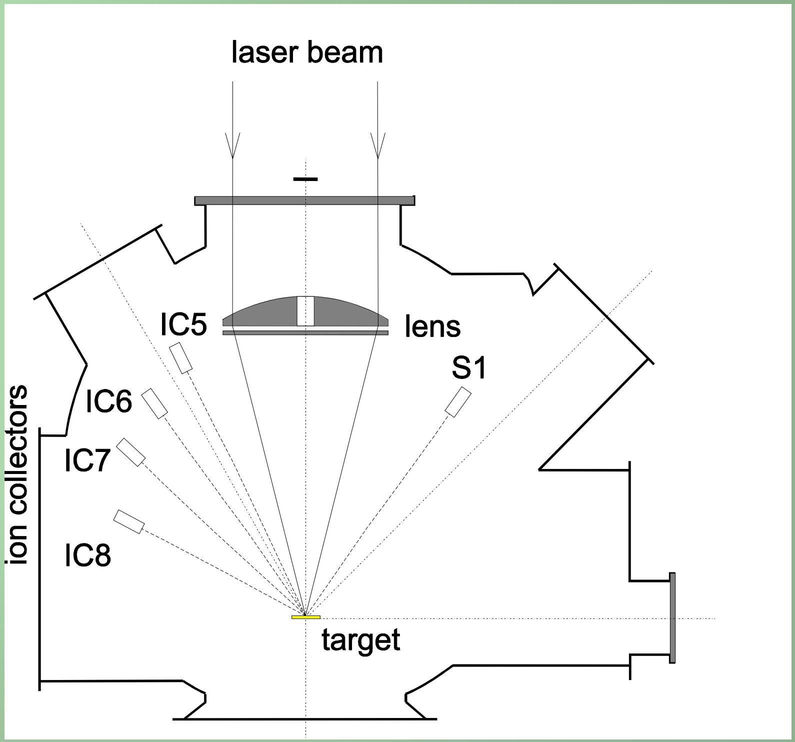
In our experiment we investigated the ***ion and x-ray emission*** from targets irradiated by means of the PALS laser system operating at a pulse energy of about ***100 J.***

The ***lens-target distance*** was changed in the broad range up to ***± 3 mm*** to obtain the full picture of the observed phenomena.

We hope the acquired overall picture of the observed phenomena will become useful in ***interpretations of our experimental of results.***

EXPERIMENTAL *SET-UP*

- The laser operated at the ***fundamental frequency (***wavelength 1.315 μm.) and at 0.4-ns pulse energy of ***~100 J***.
- The ***focus position*** was change in the range of ***±3 mm*** which resulted in changing the **laser *spot diameter from ~70 to ~1300 μm*** and the ***laser pulse intensity from 2x10^{13} to 7x10^{15} Wcm^{-2}*.**
- The laser beam was focused **perpendicular to the Ag or Ta target** surface.



Ion collectors were placed in the experimental chamber at different distances (from 42 to 60 cm) and angles (from 23^{o} to 62^{o}).

The ***X-ray measurements*** were performed with the use of ***6 photodiodes*** covered with different filters and located at different distances from target.

The photodiodes were supplied from ***small batteries*** which are less sensitive to the ***external noise*.**

CHARACTERISTICS OF THE PHOTODIODES

For the measurement of ***soft component*** BPYP03 and BPYP03s photodiodes were used, which are made of low-resistance silicon, and are characterised by an ***active layer*** of about ***2 μm*** (at 20-V bias) and a ***dead layer*** of about ***0.15 μm.***

For the measurement of the ***harder component*** (up to 20 keV) three FLM photodiodes were used. They are of ***380-μm. active-layer*** thickness and of ***25 mm^2*** active surface.

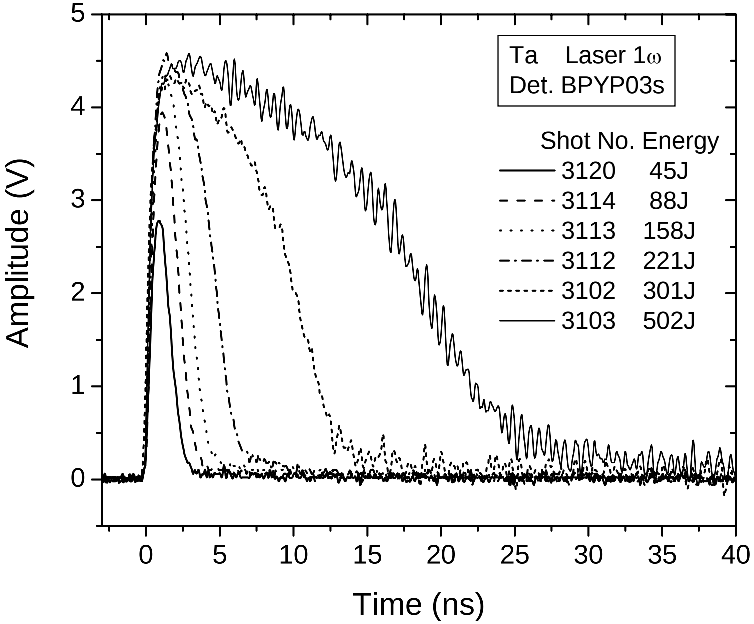
The ***fastest detector*** used in this study was BPYP42 photodiode of ***40-μm. active layer*** (at 100-V bias). The rise time of the detector was only ***300 ps*** due to the ***low surface (0.1 mm^2)*** and resulting from it a low internal capacitance.

photodiode / head type	active layer [μm] (bias)	rise time [ns]	active area [mm^2]	x-ray filter	ranges of sensitivity [keV]	Distance [cm] / remarks
BPYP03	2 (20V)		7.56	7 μm Al	0.9-1.5 (2.4-7.1)	154 / detect. for **soft X rays**
BPYP03s	2 (20V)	3	0.874	3 μm Al	0.7-1.5 (1.9-5.5)	277 / **fast** detect. for **soft X rays**
BPYP42	40 (70V)	**0.3**	**0.1**	54 μm Al	5.5 – 15.7	87 **very fast** detect. for **hard X-rays**
FLM	380		25	1.2 mm Be + 7 μm Al	5.1-20.0	154 / detect. for **hard X-rays**
FLM/integ	380		25	14 μm Al	1.3-1.5 (4.2-19.7)	120 / detect. for **hard X-rays**
FLM/integ	380		25	14 μm Al	1.3-1.5 (4.2-19.7)	164 / detect. for **hard X-rays**

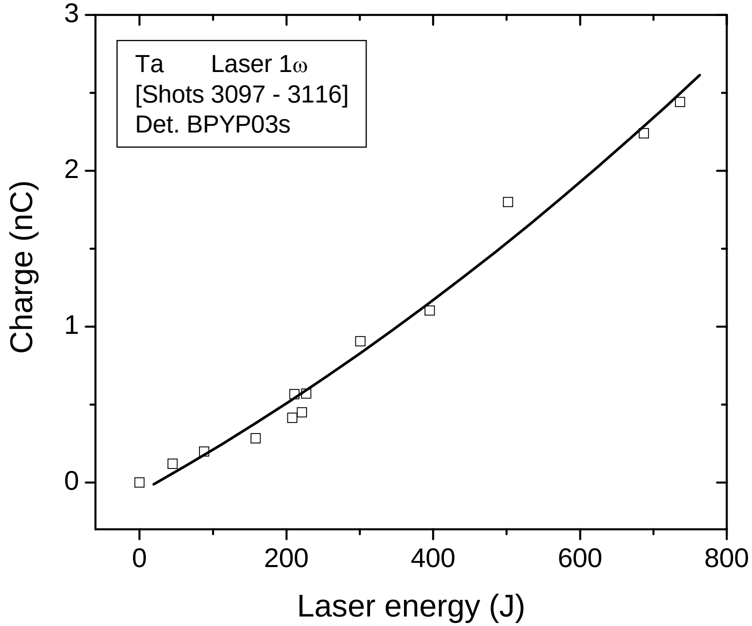
The detectors for the ***soft x-ray component*** (BPYP02 and BPYP03s) exhibit ***two ranges of sensitivity:*** at about 1 keV and at about 4 keV, but the contribution from the ***second one is low importance*** because ***intensity of x-ray radiation*** is ***dropping fast*** with rising x-ray energy.
The output signals from two ***FLM/integ*** photodiodes ***were integrated*** on an external capacitor.

OVERLOADING OF THE SOFT X-RAY DETECTORS

- The ***FLM photodiodes operate without a visible distortion up to laser pulse energy of 740 J.***
- A distinct ***saturation*** (broadening) ***of the recorded signals*** appears ***above 200 J*** in the case of ***BPYP03s photodiode.***
- Detectors such as BPYP03 or BPYP03s are mostly exposed to ***overloading*** because the soft radiation interacts in a ***very thin active layer***, which results in the generation of ***high density of charge carries*** which causes ***weakens the electric field and delays the charge collection.***
- In the case of detectors from materials of prolonged lifetime of carriers (e.g. BPYP03s photodiode) ***no saturation effects were noticed for*** signals obtained by the ***integration of the area under a response peak.***
- The ***useful dynamic range of photodiode*** may be extended by changing the method of collecting the output signals, ***from the time resolving to the time integrating one.***



An example of BPYP03s photodiode overloading.



Response of BPYP03s photodiode to x-ray pulse, expressed as the charge collected from the detector, versus laser energy.

3. Correlation of the x-ray and ion emissions from high-Z plasmas generated by a high energy PALS laser system

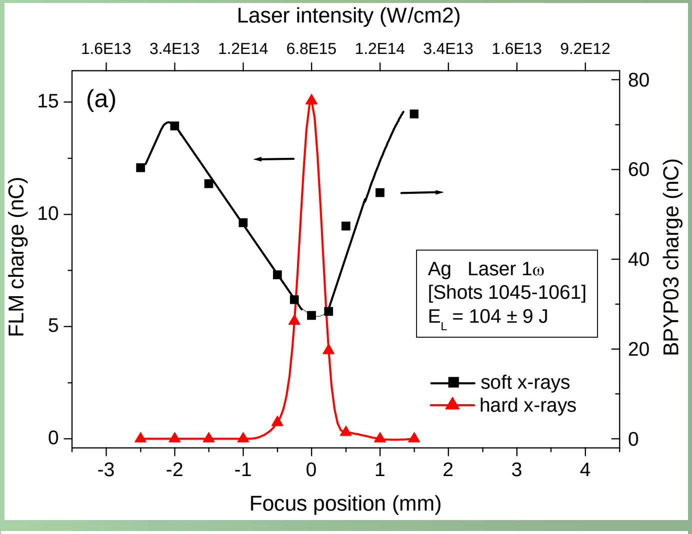
SOFT AND HARD X-RAY EMISSIONS FROM Ag (A) AND Ta (B)TARGETS AS A FUNCTION OF LASER FOCUS POSITION AND LASER INTENSITY

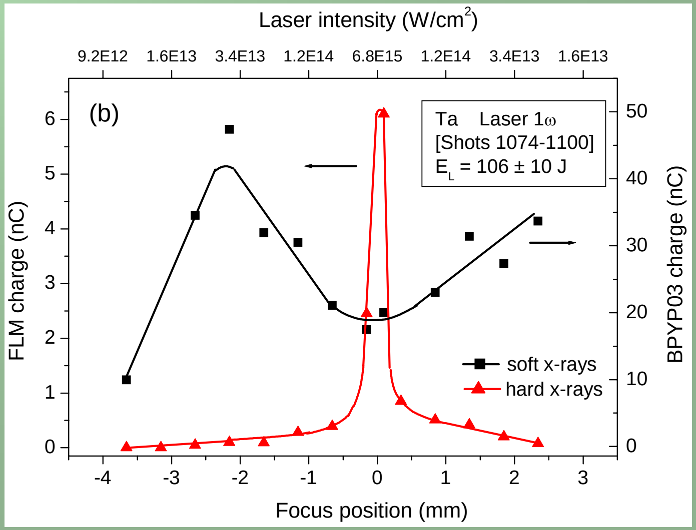
In this case the X-rays were measured by the ***BPYP03*** and ***FLM photodiodes*** filtered by ***7 μm Al and 1.2 mm Be***, respectively.

Detectors were placed at a distance of ***154 cm*** from the target.

Laser energy was ***105± 10 J*** (at the wavelength of 1.315 μm.).

The x-axis scales have been ***normalised*** *(by shifting) to establish the hard x-ray maximum at "0" focus position.*
Negative *values on x-axis imply that the laser focus is* ***in front*** *of the target surface.*





3. Correlation of the x-ray and ion emissions from high-Z plasmas generated by a high energy PALS laser system

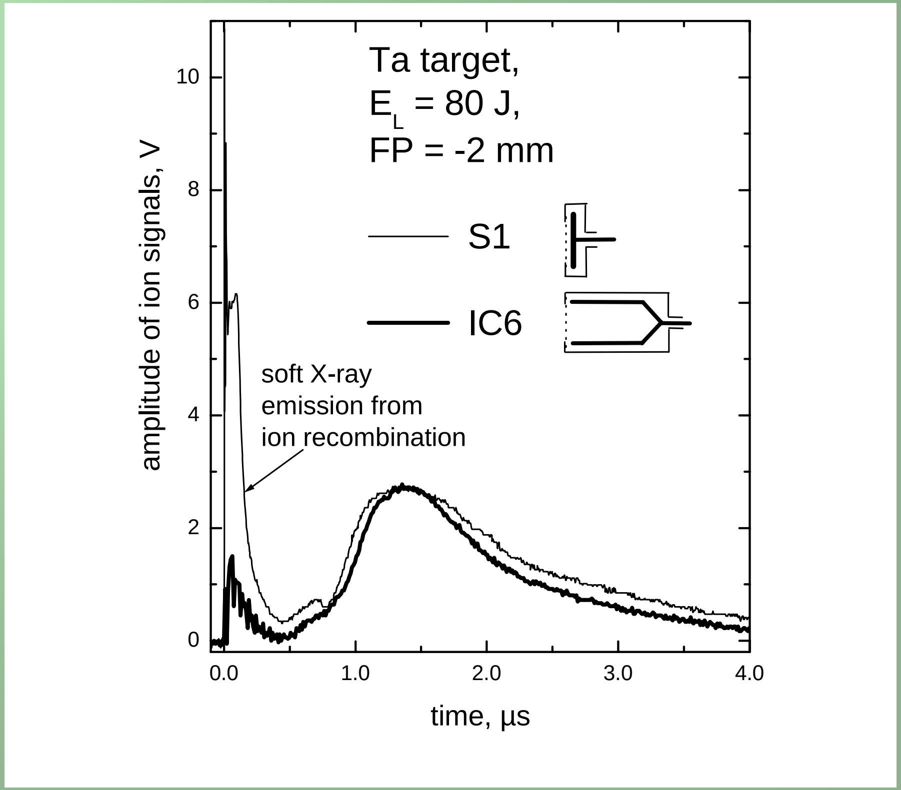
COMPARISON OF SIGNALS FROM EMISSIVE (S1) AND NON-EMISSIVE (IC6) ION COLLECTORS (after normalisation to the same distance)

Two types of collectors were used: non-emissive ones - IC5-IC8 and a standard one S1

- The responses to the ***thermal ions at the time about 1.2 µs are very similar,*** but there is a big difference in response to the ***photopeak and the fast component*** which appears immediately after the photopeak and spreads ***up to 0.5 µs.***

- As the non-emissive collector is practically non-sensitive to the ***fast component***, we conclude that it must come from ***soft x-ray radiation*** that is produced in expanding plasma by the process of ***recombination.***

- The trace of a group of ***light contaminant ions and fast heavy ions*** is seen at about ***0.7 µs.***



- The ***much slower component*** of low amplitude of the IC signal which appears later than ***4 µs*** was omitted for simplification.

3. Correlation of the x-ray and ion emissions from high-Z plasmas generated by a high energy PALS laser system

CHARACTERISTICS OF X-RAY AND THERMAL ION EMISSION IN DEPENDENCE ON A FOCUS POSITION

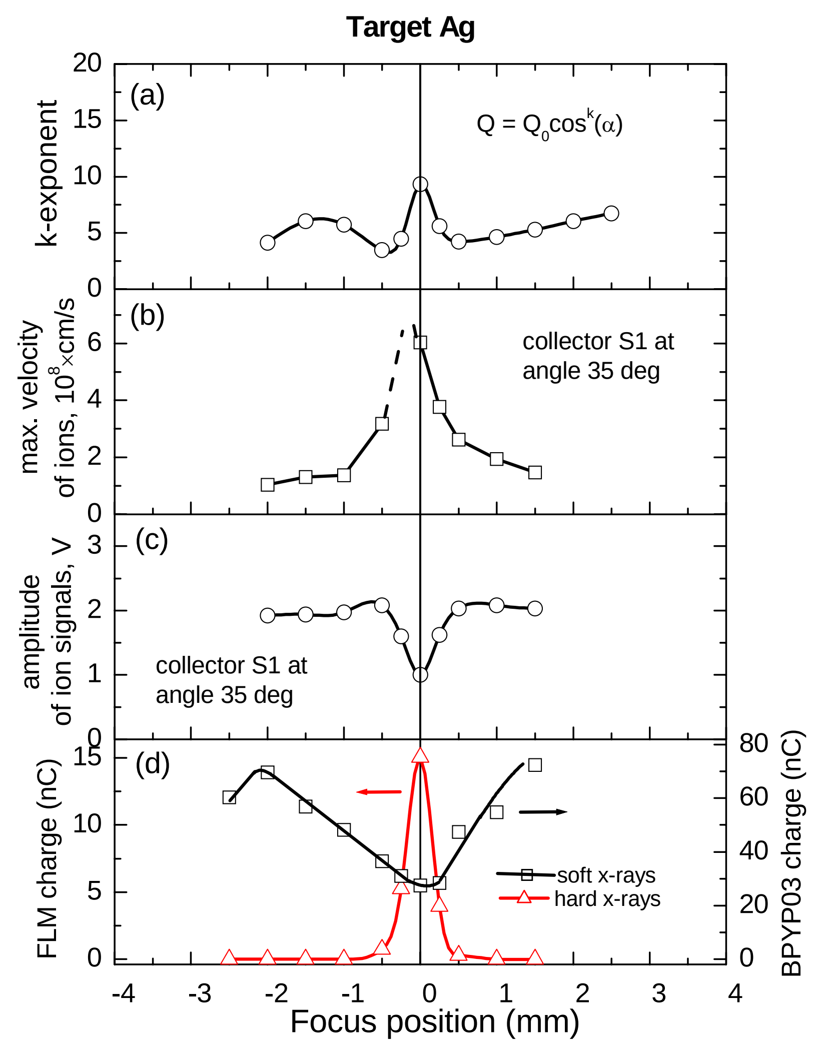
The ***soft and hard X-ray emission*** measured by ***BPYP03*** and ***FLM photodiodes***, filtered by by 7 μm Al and 1.2 mm Be, respectively, ***differs to a great extend.***

The emission in the ***soft channel*** is related to the ***volume of the plasma***, which becomes the smallest just the case of sharp focusing.

The peaking of the ***hard X-ray emission*** indicates the most intense production and then interaction of ***fast electrons*** with surrounding plasma and target material.

The hard x-ray emission is a of ***a threshold nature*** and for Ag plasma starts at intensity about ***6.3 x 10^{14}W/cm^{2}.***

x-scale** has been normalised to establish the **hard X-ray maximum at '0' focus position.



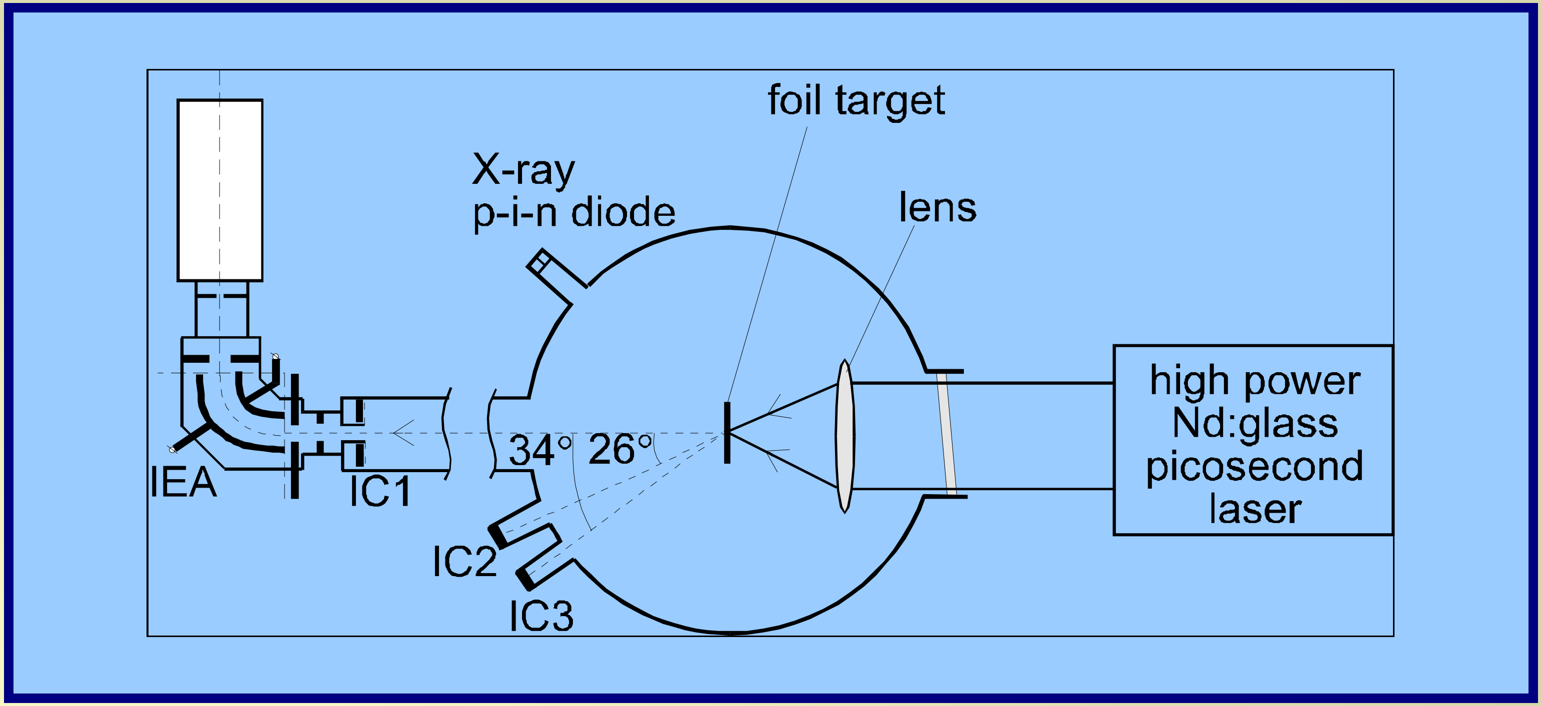
4. FAST ION GENERATION IN THE PLASMA PRODUCED BY A 1-ps HIGH INTENSITY LASER PULSE

4. Fast ion generation in the plasma produced by a 1-ps high intensity laser pulse

EXPERIMENTAL SET-UP FOR STUDIES OF THE ION STREAM GENERATED WITH THE USE OF THE 1-ps TERAWATT LASER SYSTEM

4. Fast ion generation in the plasma produced by a 1-ps high intensity laser pulse

SCHEME OF THE EXPERIMENTAL ARRANGEMENT



IEA – electrostatic ion-energy analyzer with windowless electron multiplier;
IC1, IC2, and IC3 – ion collectors.

THE 1-ps TERAWATT LASER SYSTEM FOR STUDIES OF THE LASER-MATTER INTERACTION AT INTENSITIES UP TO 10^{17} W/cm^2

4. Fast ion generation in the plasma produced by a 1-ps high intensity laser pulse

Forces accelerating ions in plasma

gas dynamic (termokinetic) forces: **$p = nkT$**
electrostatic (created due to a separation of charges in plasma): **$\underline{F} = q\,\underline{E}$**
ponderomotive (created due to inhomogeneity of the laser field and/or plasma): **$\underline{F_p} \propto \underline{\nabla} E^2$**

Ranges of laser intensity in short-pulse experiments

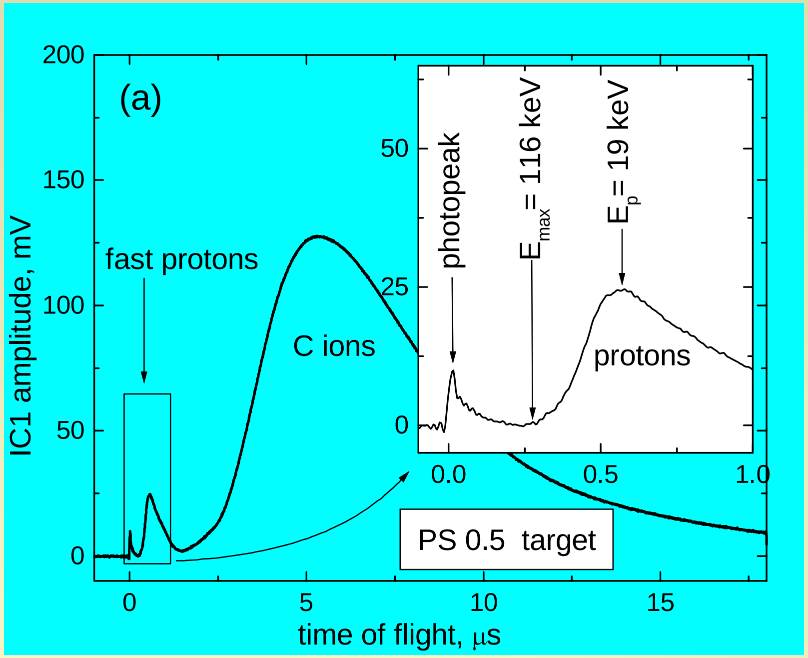
Relativistic intensity: **$I_{rel} \approx 4.1 \times 10^{18}/\lambda^2$** [W/cm^2, μm]
At $I = I_{rel}$, the oscillation energy of the electron is equal to its rest energy mc^2

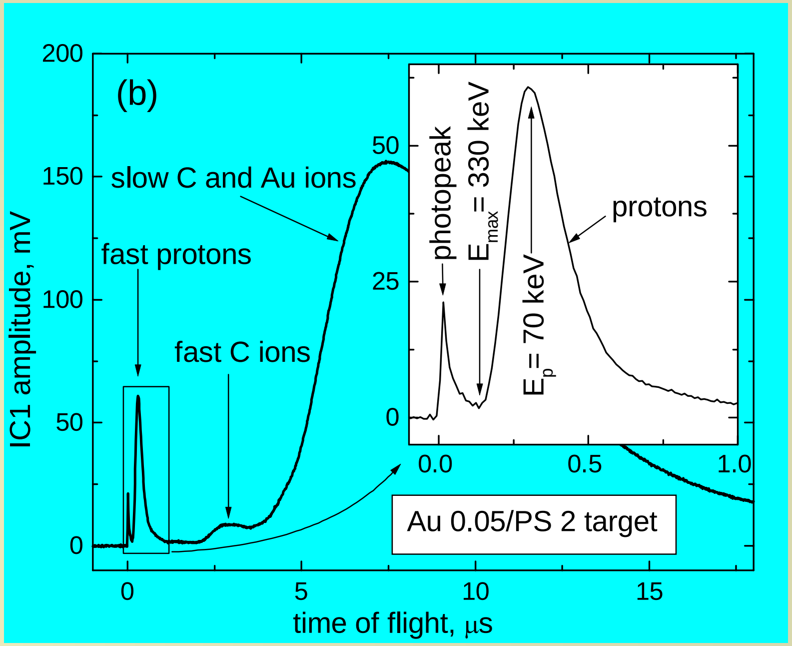
- subrelativistic range, **$I \ll I_{rel}$** $I < 10^{18}$W/cm^2 at $\lambda \approx 1\mu m$
- relativistic range, **$I \sim I_{rel}$** 10^{18}W/cm$^2 \leq I \leq 10^{20}$W/cm^2 at $\lambda \approx 1\mu m$
  (LLNL, RAL, LULI, LLE)
- ultrarelativistic range, **$I \gg I_{rel}$** $I > 10^{20}$W/cm^2 at $\lambda \approx 1\mu m$
  (LLNL)

IPPLM experiments were performed at ***subrelativistic intensities***.

4. Fast ion generation in the plasma produced by a 1-ps high intensity laser pulse

IC1 COLLECTOR SIGNALS FROM THE Au0.05/PS2 TARGET (a) and THE PS0.5 TARGET (b). The magnified portions of the signals show the proton peak.

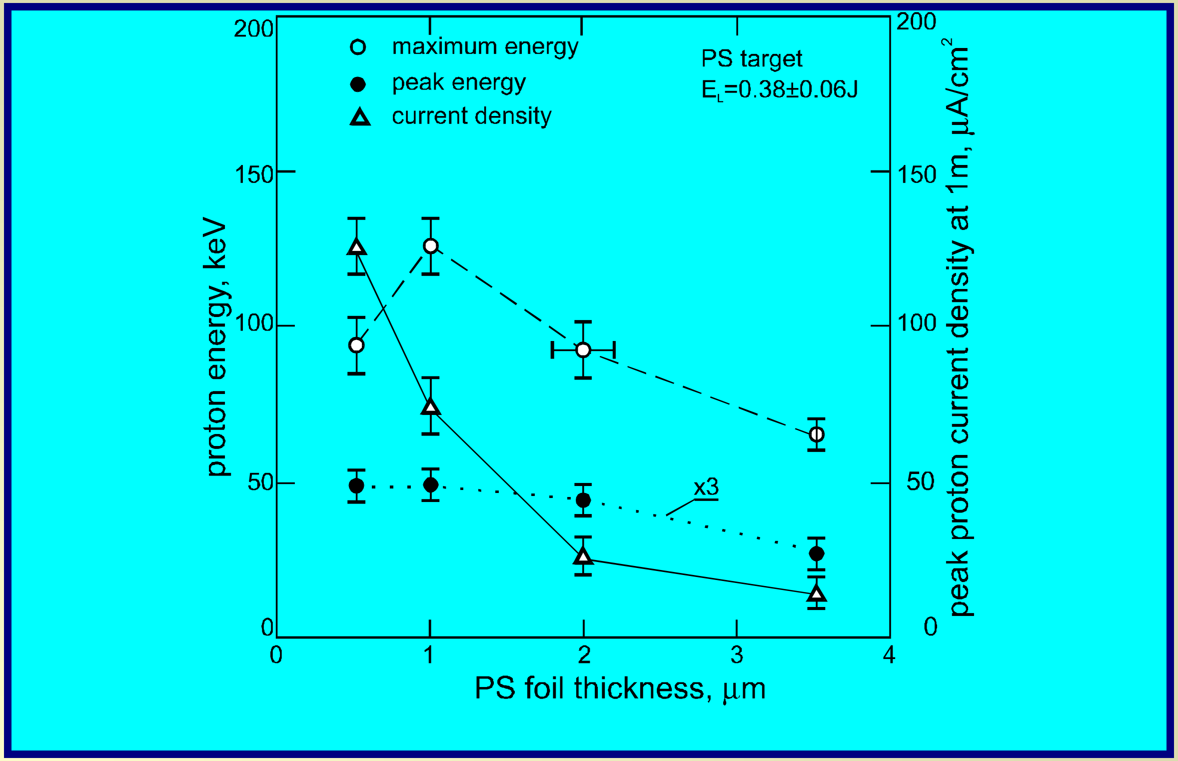




IC signal contains ***fast protons*, C ions** (C^{+1} – C^{+4}) and **Au^{+1} ions**.
Both the maximum and mean proton energies as well as the peak proton current density can be determined from IC signal.

4. Fast ion generation in the plasma produced by a 1-ps high intensity laser pulse

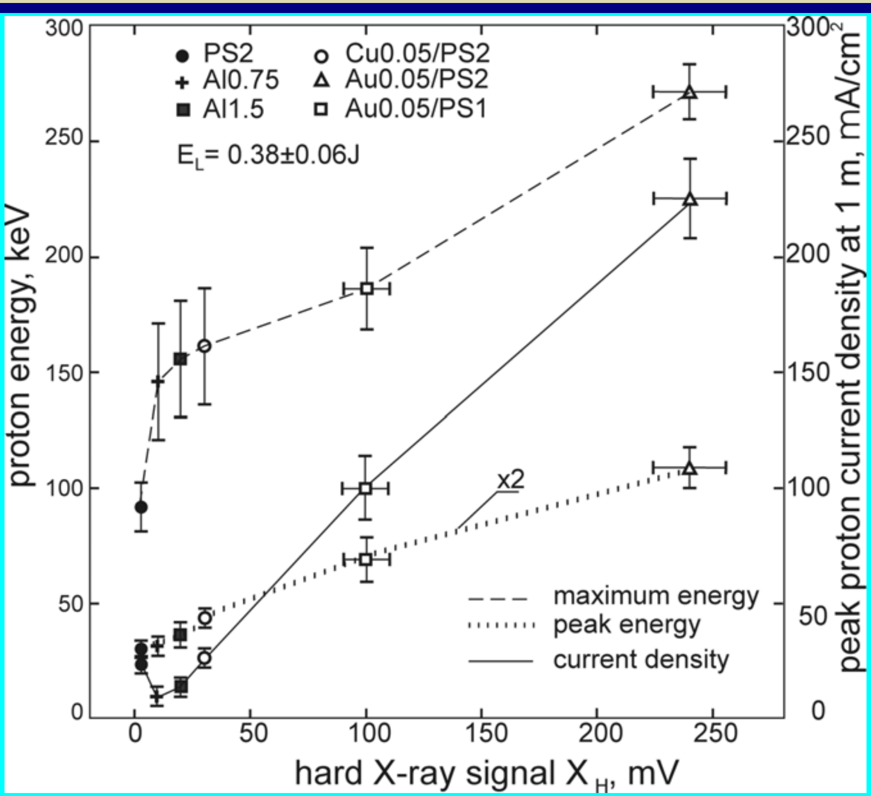
PARAMETERS OF PROTON BEAMS FROM PS TARGETS AS A FUNCTION OF THE TARGETS THICKNESS



Parameters of proton beams significantly depend on a total target thickness.

4. *Fast ion generation in the plasma produced by a 1-ps high intensity laser pulse*

PARAMETERS OF PROTON BEAMS FROM VARIOUS TARGETS IN CORRELATION WITH X-RAY SIGNAL AT FIXED LASER ENERGY



Parameters of ***proton beams*** are strongly correlated with the yield of ***hard X-rays*** produced by hot electrons.

The ***highest proton energies*** and the ***highest proton current densities*** have been observed for ***double – layer targets*** with high – Z layer (Au/PS targets).

5. SUMMARY

2. Comparison of ion emission from high-Z plasmas generated by a high energy PALS laser at the fundamental and at the 3rd harmonic frequencies

SUMMARY

Using the high-intensity long-wavelength as well as short-wavelength PALS laser pulses (1315 nm and 438 nm, respectively), the production of highly charged, high-energy ions have been demonstrated, ***using IC, IEA, and solid-state track detector measurements***.
For Ta ions $z_{max} = 57$ ***and*** $E_i > 20$ ***MeV.***

The ion collector signals recorded at higher laser pulse energies clearly show the existence of ***three separate ion groups***: fast, thermal and slow.

At high laser pulse energies, $E_L > 200$ J, ***fast ion current density*** attains $j_{max.} \sim 20$ mA/cm^2 at the distance of 1 m from the target.

An efficient production of highly charged high-energy ions, by an intense short-wavelength laser pulse with suggests that the mechanisms of the fast ion generation with the use of such laser pulses should be clarified talking into account that the ***classical process of fast ion acceleration by hot electrons*** escaping from plasma ***decreases with the decreasing wavelength***.

Thus, in the case of short-wavelength laser-plasma interactions other phenomena only weakly dependent on the laser wavelength e.g. ***ponderomotive forces and self-focusing*** of laser radiation may contribute to the ***acceleration of ions*** in the plasma.

3. Correlation of the x-ray and ion emissions from high-Z plasmas generated by a high energy PALS laser system

SUMMARY

It was shown that the silicon photodiodes can be applied for reliable measurements of ***high-intensity X-ray*** emission in the range of ***1 - 20 keV*** provided from the plasmas produced with the use of the PALS laser system at different experimental conditions.

The detectors for ***hard radiation are not overloaded*** up to the charge surface density of 84 nC/cm^2.

The detectors for ***soft x-ray radiation*** (< 1.5 keV), of a thin active layer, ***are mostly exposed to overloading***, which manifests itself in broadening the output pulses.

However, ***if the signals undergo integrating***, the detectors' response seems to be ***linear*** up to type charge surface density of 900 nC/cm^2. The detectors are then useful up to 740 J of laser energy, as well.

The parameters of both ***X-ray and ion emissions*** change clearly depending on the lens-target separation and these changes ***are well correlated*** with each other.

The ***most radical changes*** in the emission are observed when the target is shifted into a ***close vicinity of the focal plane***, which causes the exceeding of ***a threshold level of about 6×10^{14} Wcm^{-2}*** of the laser intensity (that corresponds to the beam spot of 230 μm.).

The changes are manifested by an ***abrupt rise of hard x-ray emission, lowering the amount of ions and narrowing the angle distribution.***

4. Fast ion generation in the plasma produced by a 1-ps high intensity laser pulse

SUMMARY

- We have shown that using ***double-layer foil targets*** containing high-Z front layer and low-Z hydrogen-rich back layer, instead of commonly used single-layer targets, a considerable ***increase in energies and current of protons*** produced by an ultrashort-pulse laser is possible.

- Above ***10^9*** protons of energy ***> 100keV*** have been recorded within a cone angle about ***3°*** near the target normal at intensities ***10^{17} W/cm^2***.

- Both the ***maximum and the mean proton energies as well as the proton current*** are ***correlated with the hard x-ray*** yield and they increase with the growth of Z-number of high-Z layer.

- For ***maximizing the proton energies and/or proton current*** both total target thickness and high-Z layer thickness must be ***optimally selected***.