MSU-LPI Relativistic laser plasma laboratory
http://rlp.ilc.edu.ru

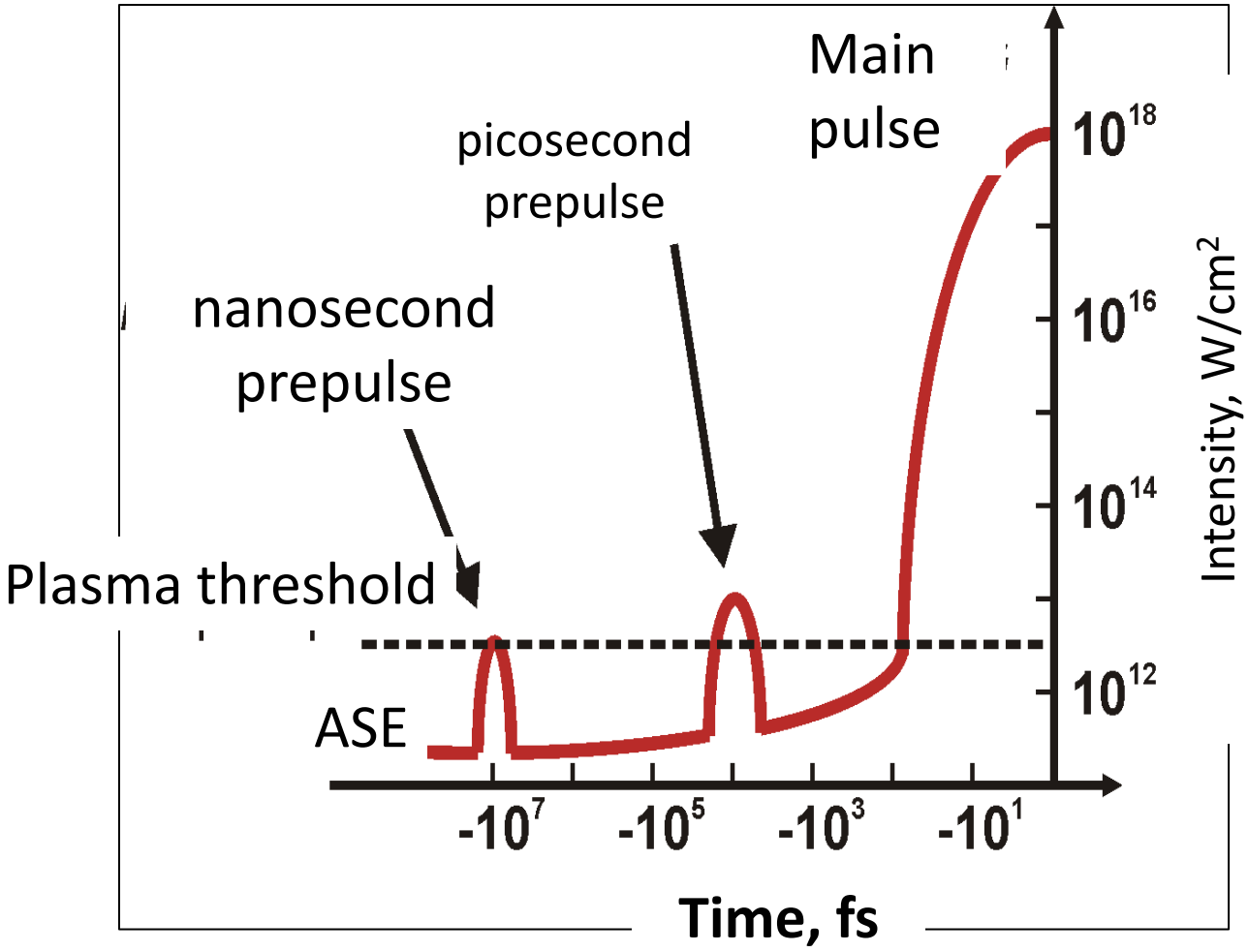
P.N.Lebedev Physical Institute of the Russian Academy of Sciences

Impact of a pre- pulse onto relativistic laser plasma interaction: electron, proton and heavy ion acceleration and surface structuring

Andrei Savel'ev

EMMI-workshop on "High energy density plasma diagnostics"
***SEPTEMBER 30 – OCTOBER 2,* 2013, DARMSTADT**

Laser pulse contrast

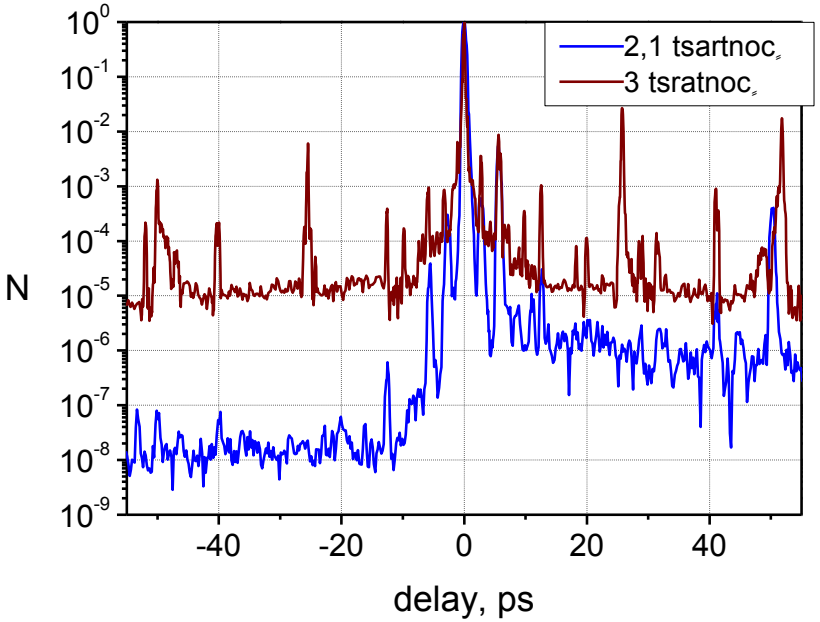


Outline

- Pre-plasma impact onto fast electron generation at high intensities – solid targets
- Pre-plasma impact onto fast electron generation at high intensities – liquid metal targets
- Pre-pulse effect onto heavy ion acceleration
- Proton acceleration at ultrahigh intensities

Contrast characterization

- Energy per pulse 1-50 mJ
- Pulse duration >35 fs
- Central wavelength 805 nm
- Repetition rate 10 Hz
- M^2 1.4-1.7



ASE

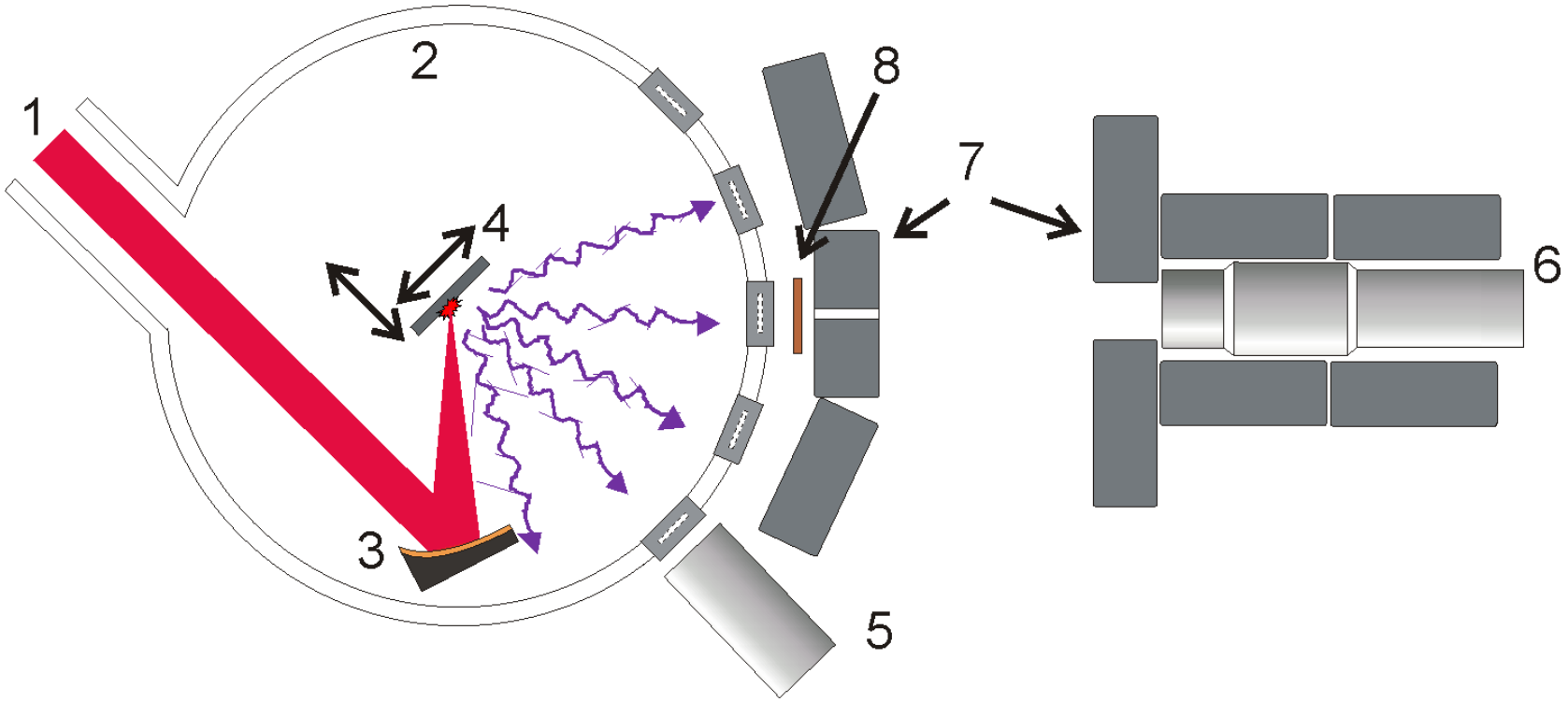
ASE level		case «1»	case «2»	case «3»
		10^{-8}	10^{-8}	10^{-5}
Picosecond prepulse	amplitude	6×10^{-7}	6×10^{-7}	5×10^{-3}
	Advancing time, ps	12	12	25
Nanosecond prepulse	amplitude	5×10^{-8}	3×10^{-4}	2×10^{-6}
	Advancing time, ns	12.5	12.5	12.5

Experimental scheme

τ= 35 -- 350 fs; λ = 800 nm; ν = 10 Hz; E = 10 -20 mJ;

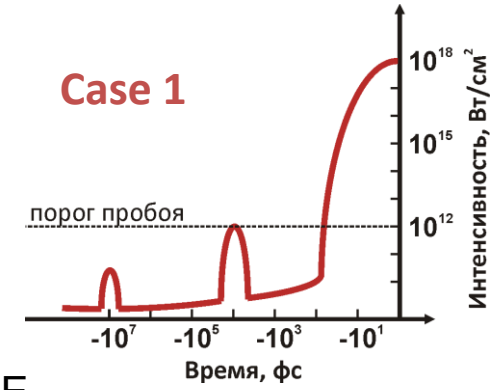
$I_{max} = 10^{17}$-2x10^{18} W/cm^2

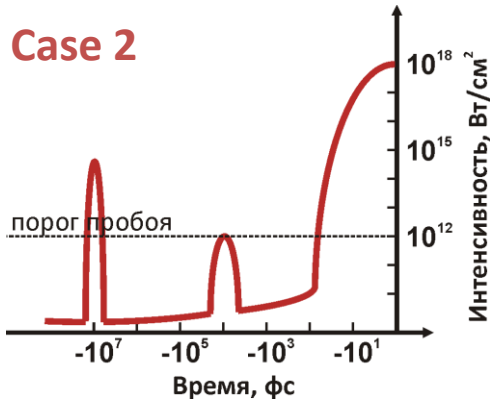
targets:
Fe, Pb, quartz glass

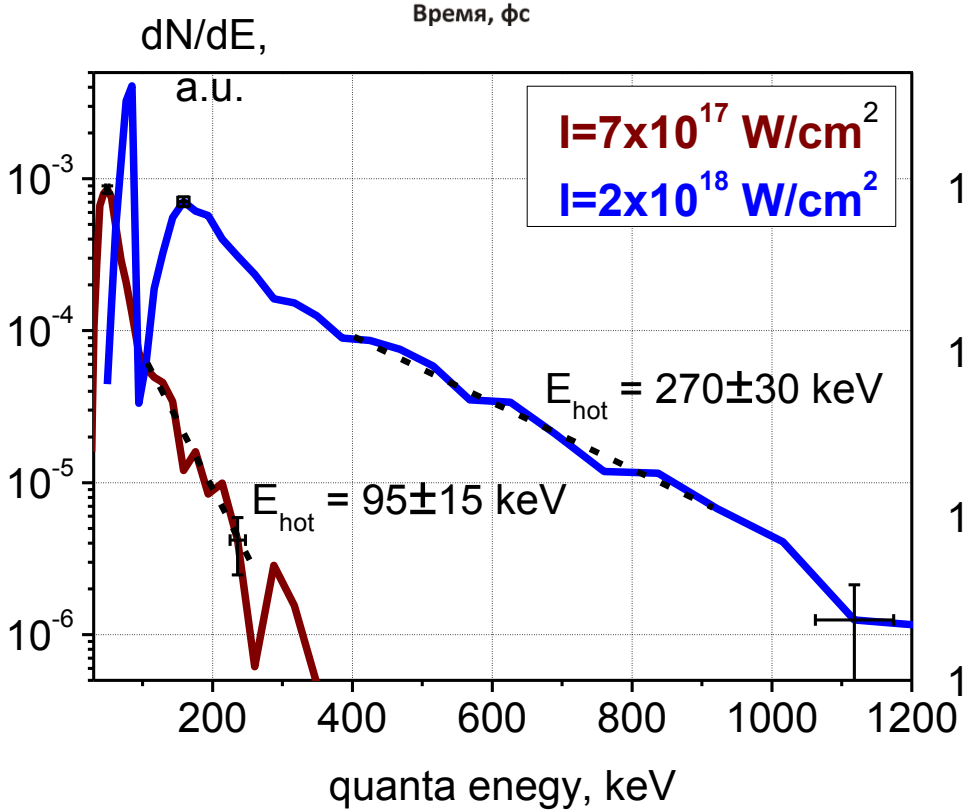


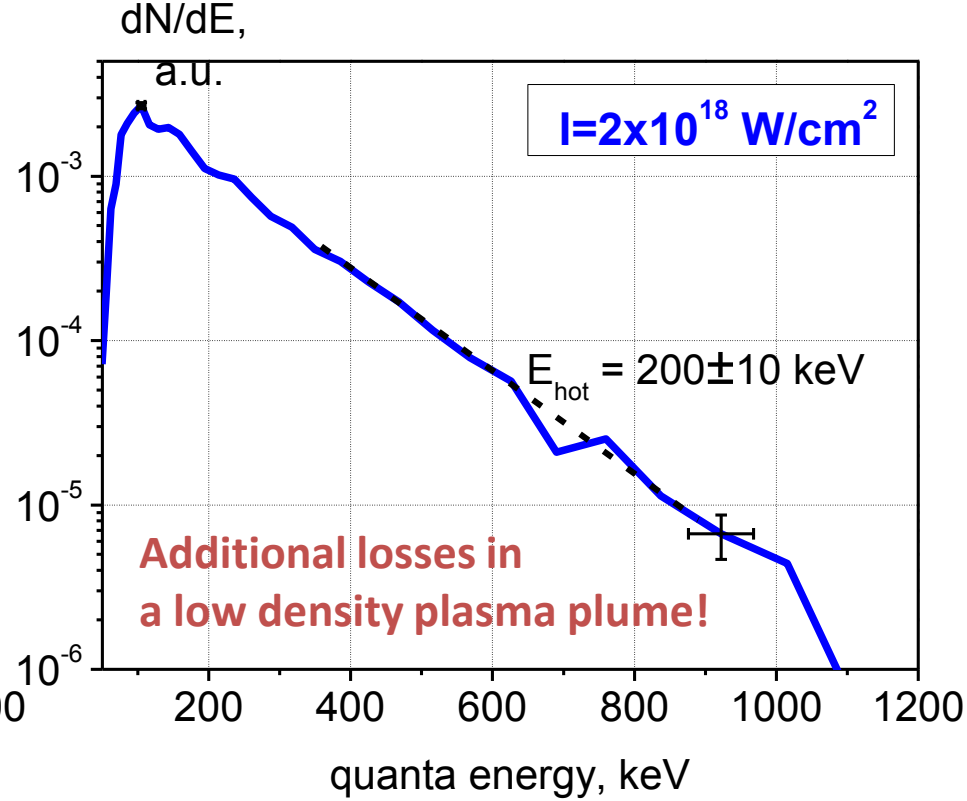
Poster paper by Konstantin Ivanov

Hard X-ray data: Fe target



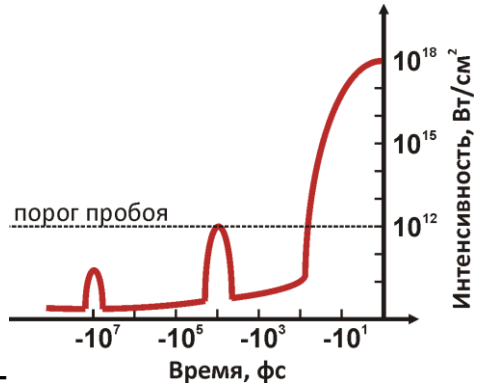




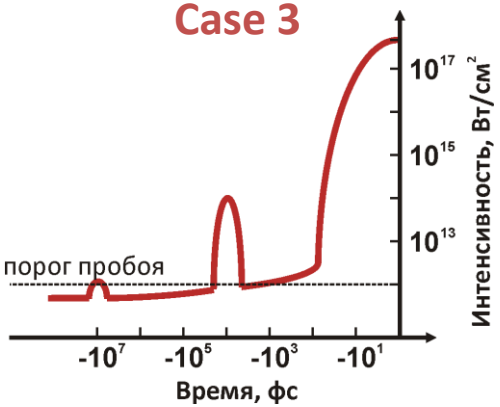


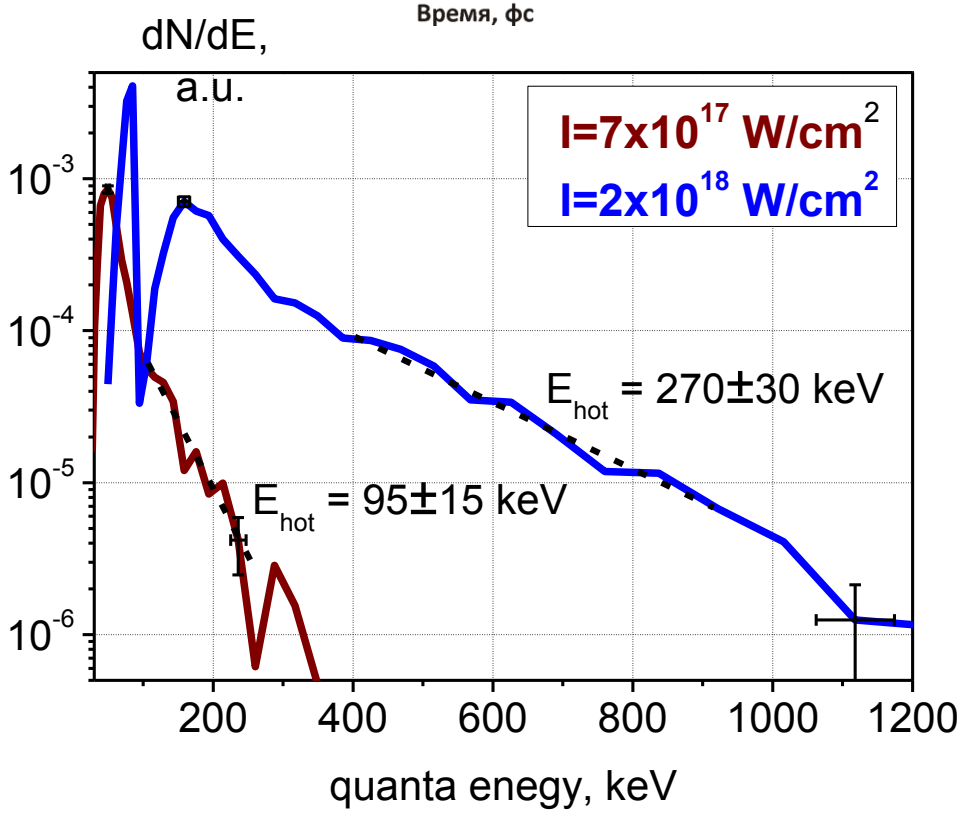
Hard X-ray data: Fe target

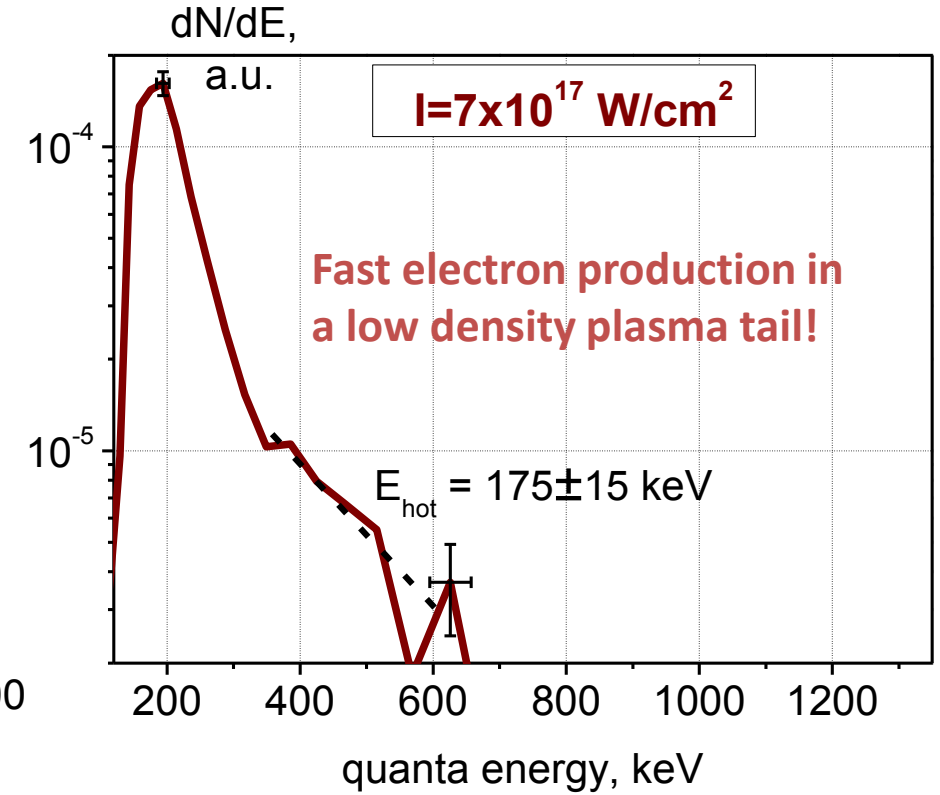
Case 1



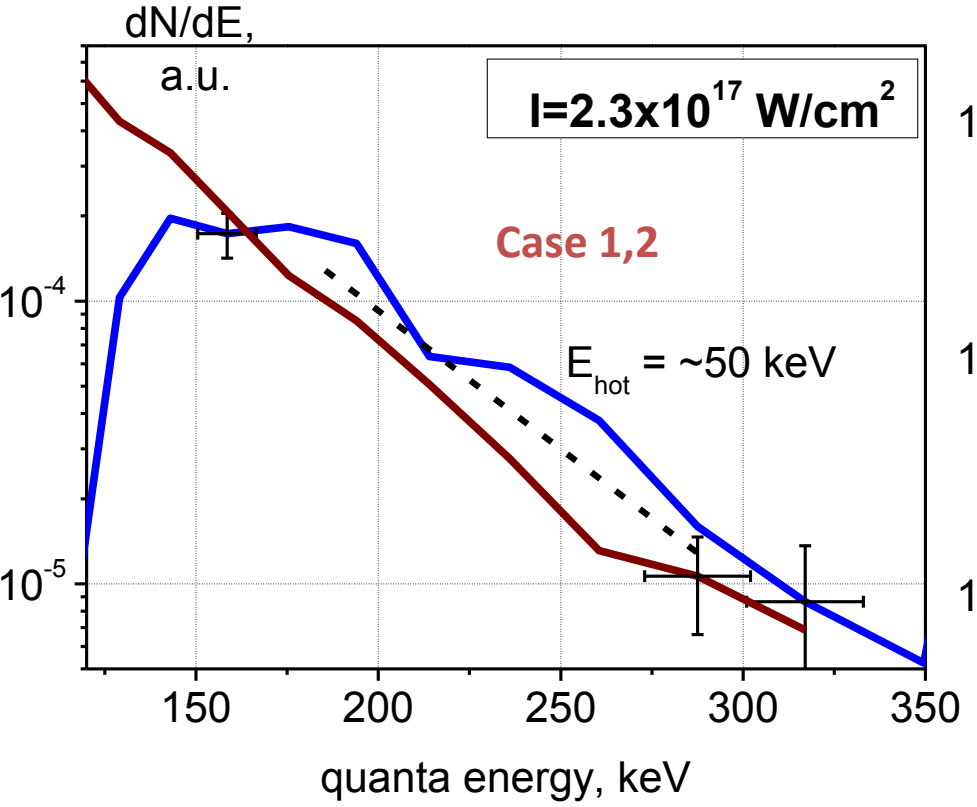
Case 3

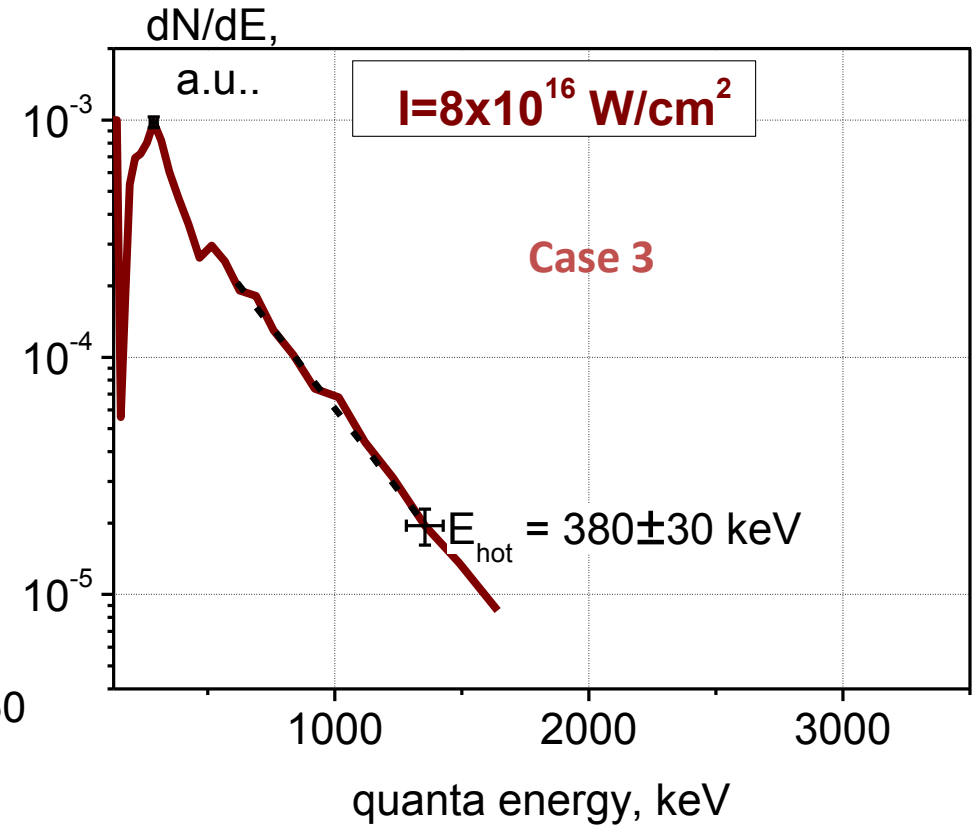






Hard X-ray data: long pulse (350 fs), Fe target

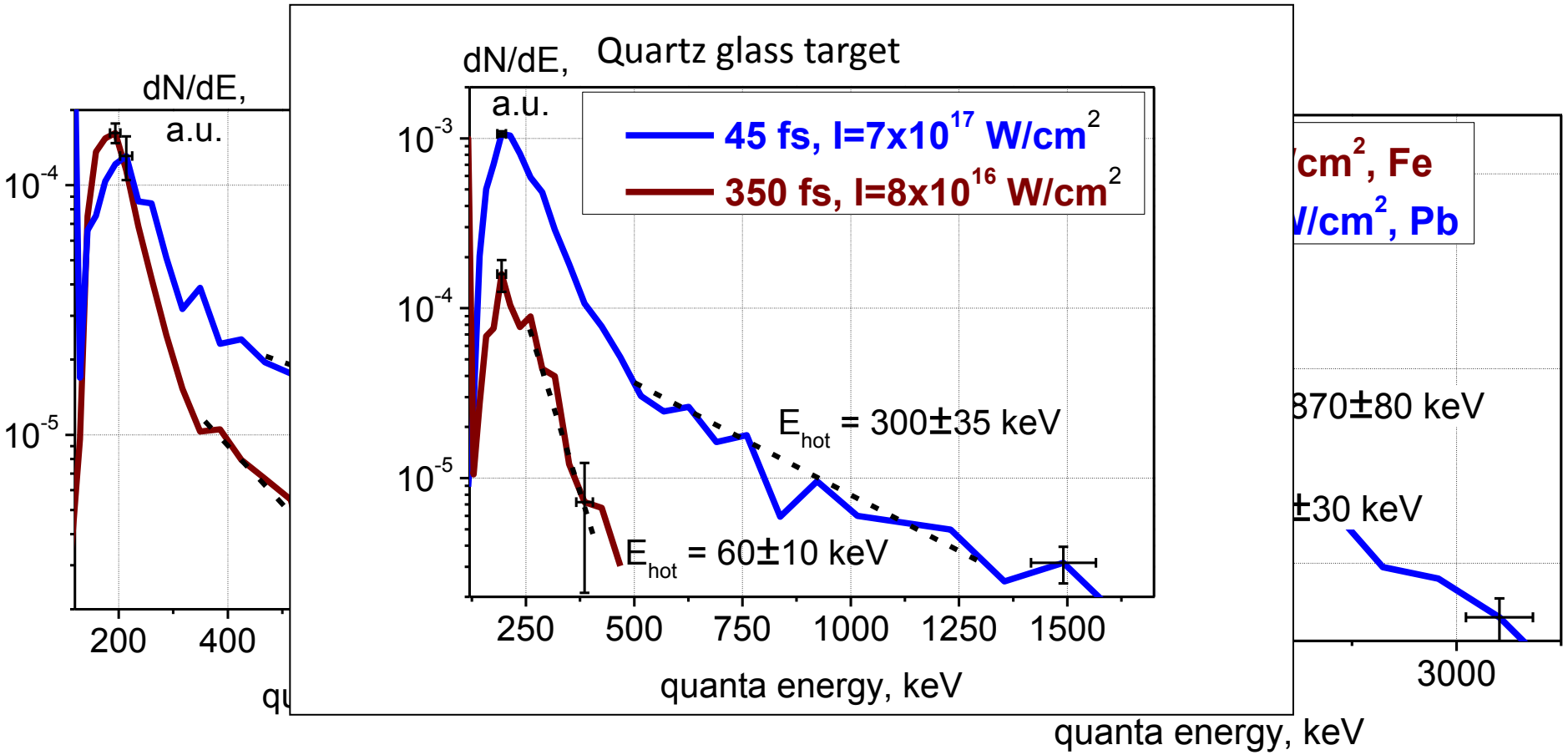




For the 45 fs pulse at 2×10^{18} W/cm^2 (nearly 10 times higher intensity)

- **Case 1: E_{hot}=270 keV**
- **Case 3: E_{hot}=175 keV**

Hard X-ray data: case 3, Fe & Pb target



$E_{hot} \sim I^{a}$

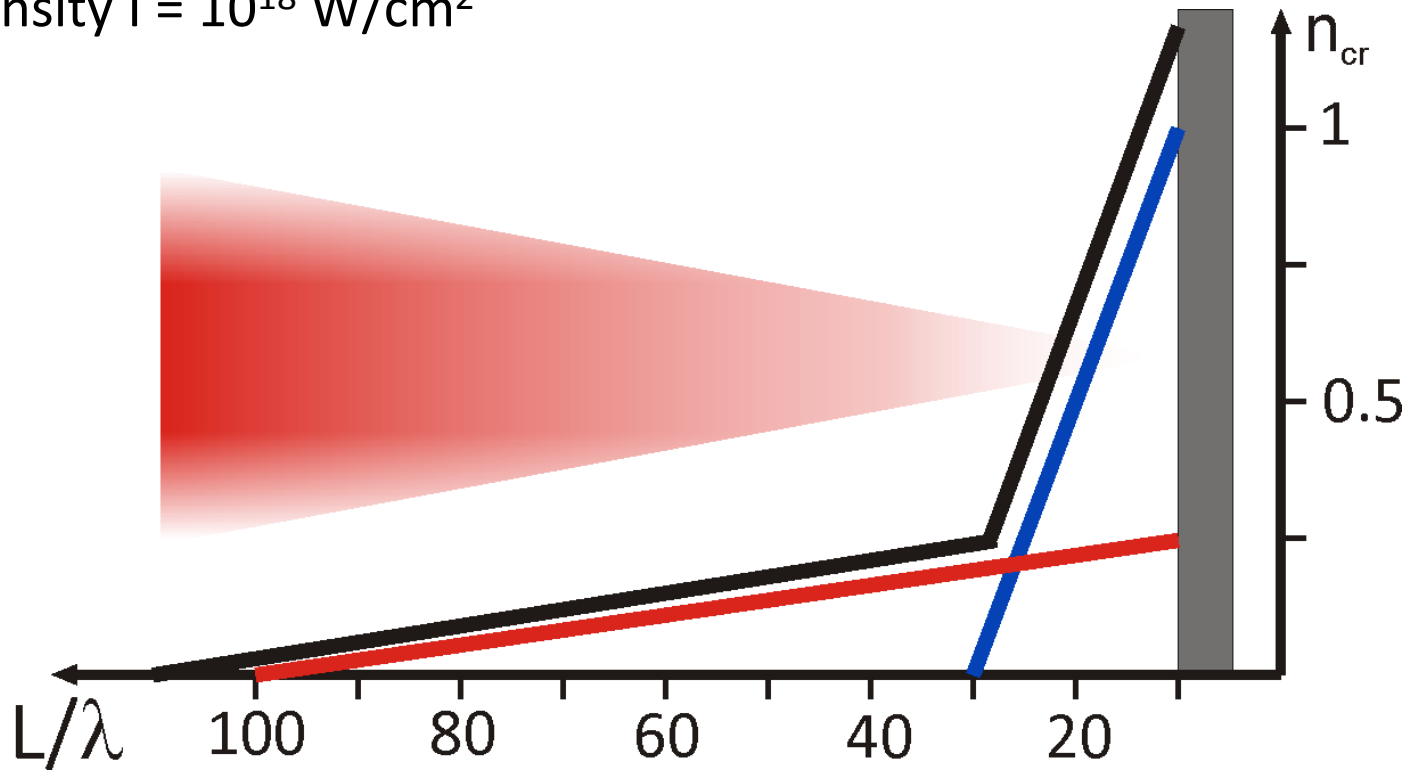
$E_{hot,\ 45\ fs} > E_{hot,\ 350\ fs}$

Parametric processes?

2D PIC modeling with Mandor code

Laser pulse

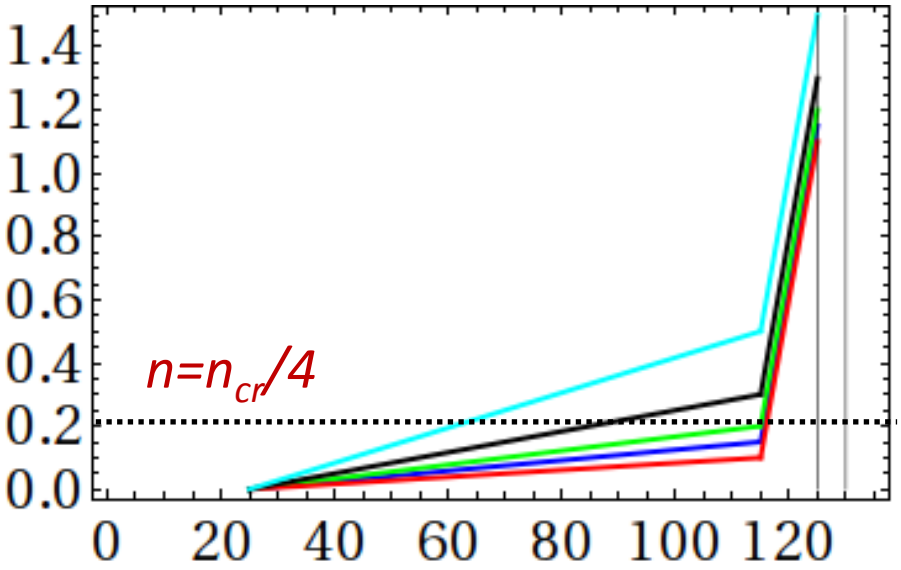
- Pulse duration 50 and 300 fs
- Plasma focal spot– 4 mcm
- Intensity I = 10^{18} W/cm^2

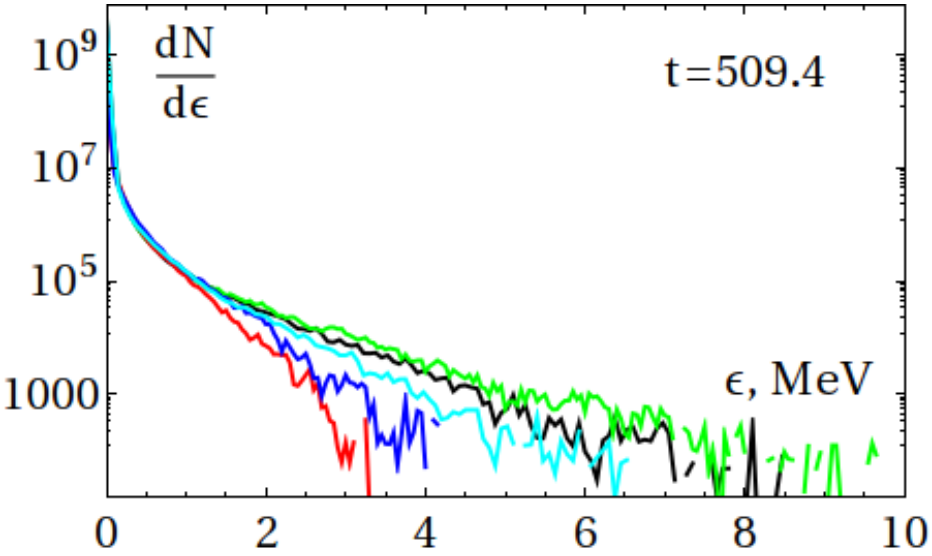


2D PIC modeling with Mandor code

Laser pulse

- Pulse duration 50
- Plasma focal spot– 4 mcm
- Intensity I = 10^{18} W/cm^2





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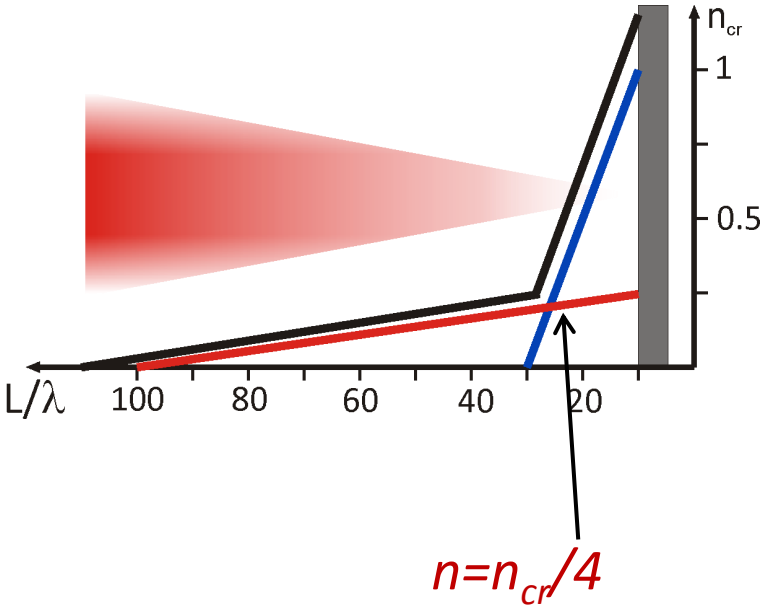
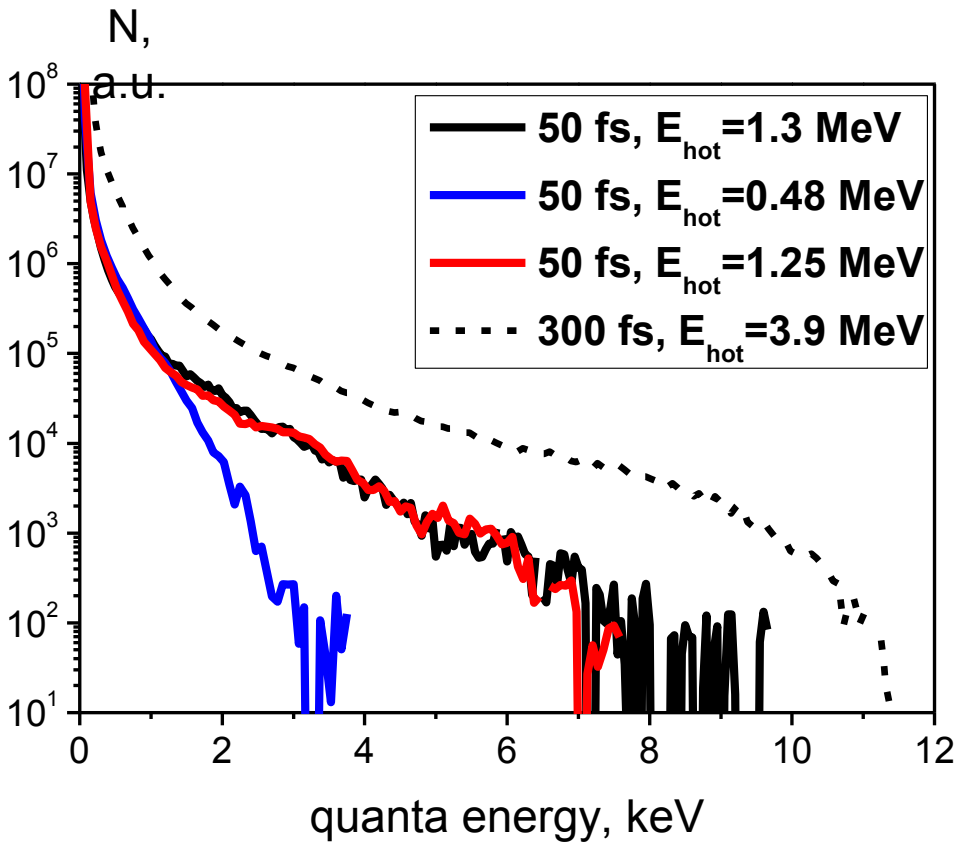
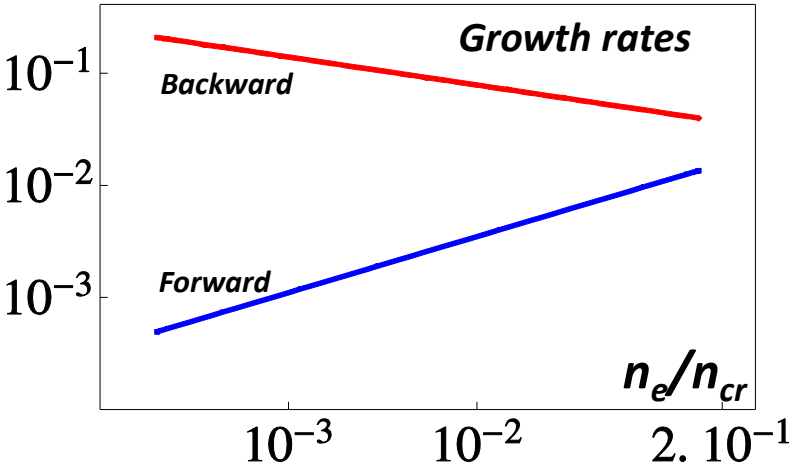




Stochastic heating in underdense plasma

Plasma waves excitation by Stimulated Raman Scattering



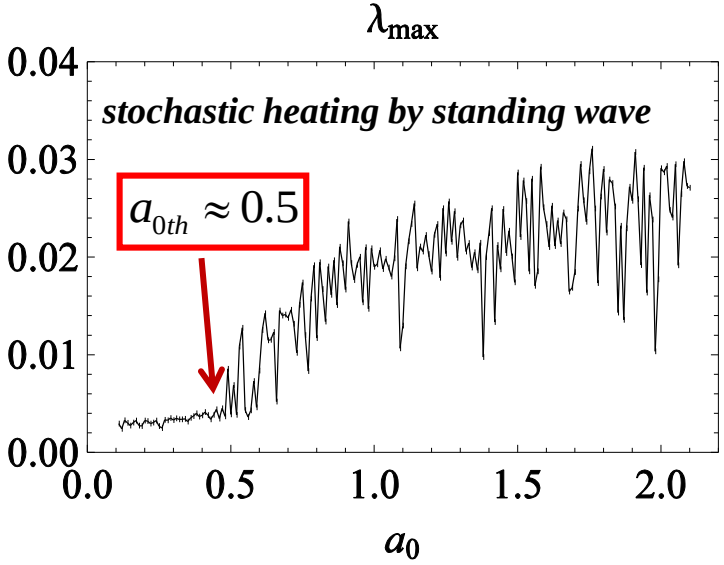
$$\omega_L = \omega_S + \omega_l \qquad k_L \to k_S \pm k_l \qquad t \to l + t'$$

Criteria of Stochastic Heating - Lyapunov exp.

$$\lambda_{\max} = \lim_{t\to\infty}\lim_{d(0)\to 0}\frac{1}{t}\ln\frac{d(\vec{x}_0,t)}{d(\vec{x}_0,0)}, \quad d \approx \exp(\lambda_{\max} t)$$

Spectrum of accelerated electrons in combined fields L+S+l waves

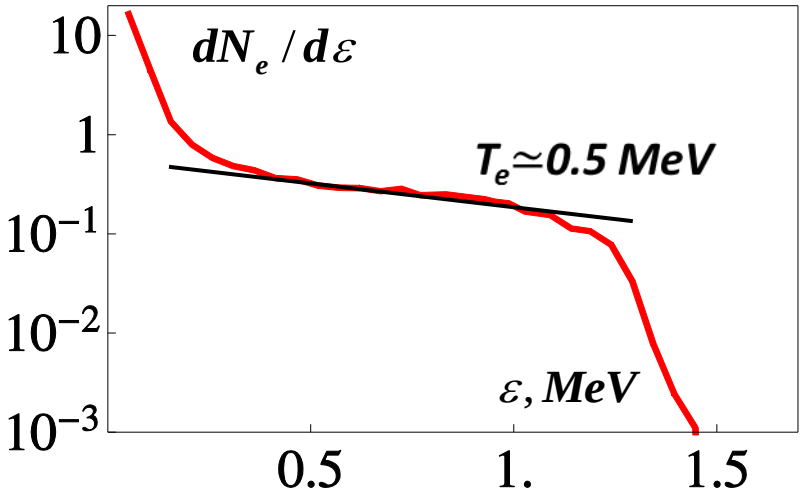
Maximum Lyapunov exponent



$I \approx 10^{17}$ W/cm^2, $a_0 \leq 0.1$, $\tau \approx 350$ fs, $L \approx 100\,\lambda$, $\lambda = 0.8\,\mu$m

$n_e < n_{cr}/4$

test particle simulations



Oral paper by Sergei Bochkarev

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- Pre-plasma impact onto fast electron generation at high intensities – solid targets
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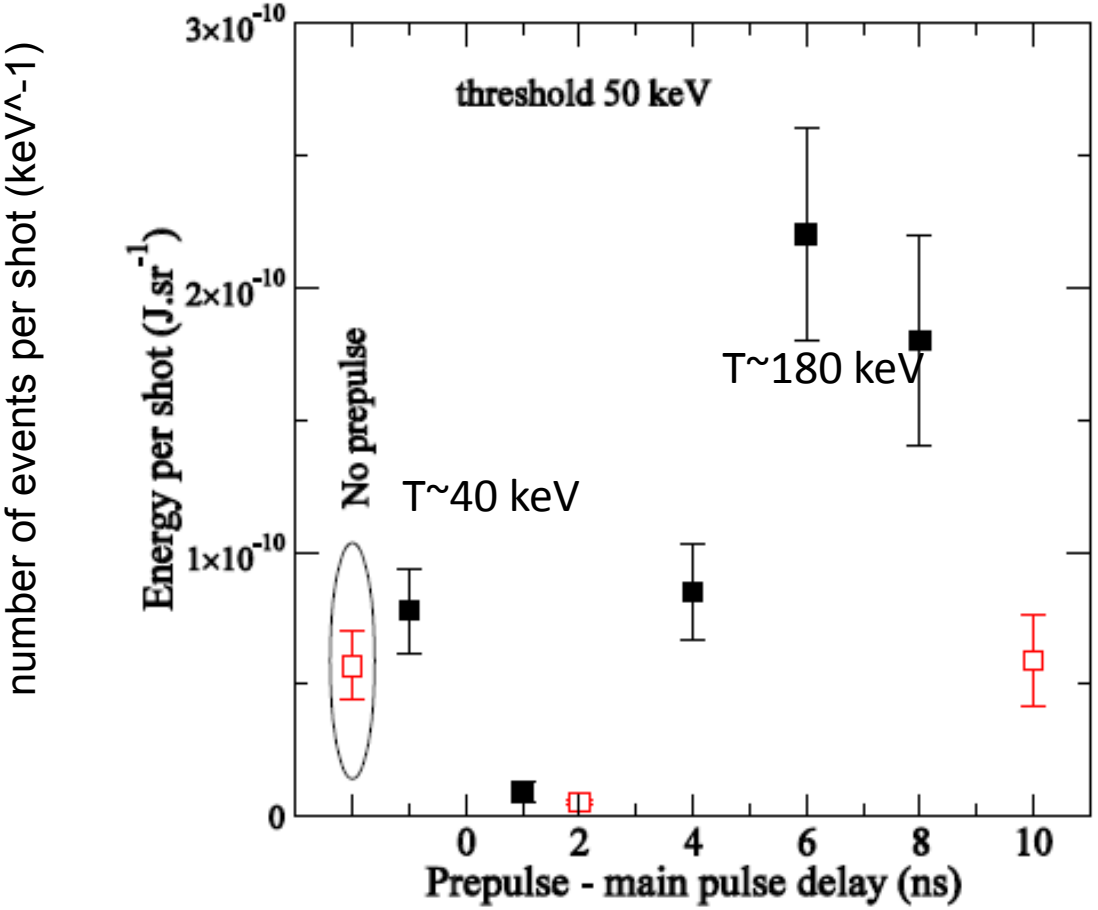
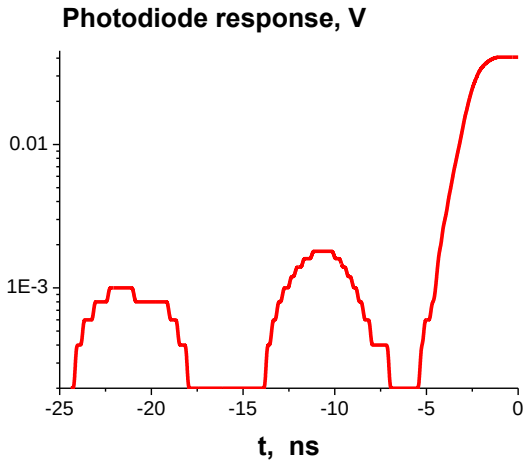
Hard X-ray yield prepulse delay dependence
("low" intensity, CELIA)

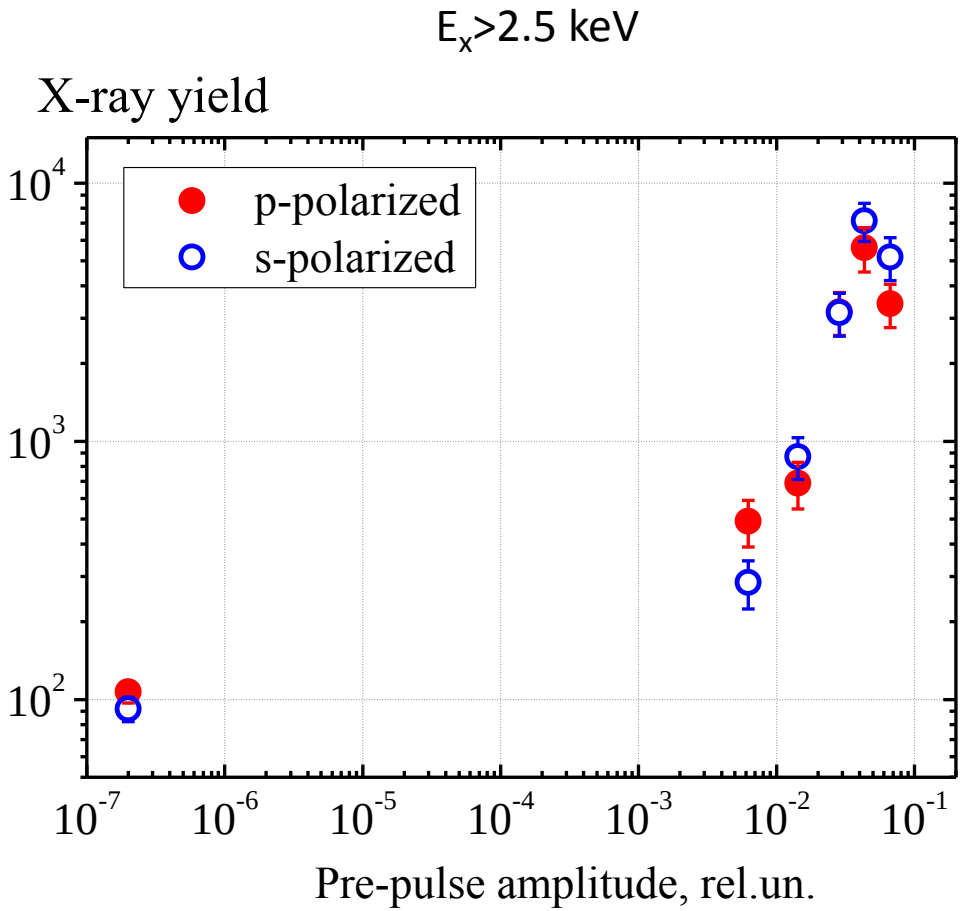
10^{17} W/cm^2



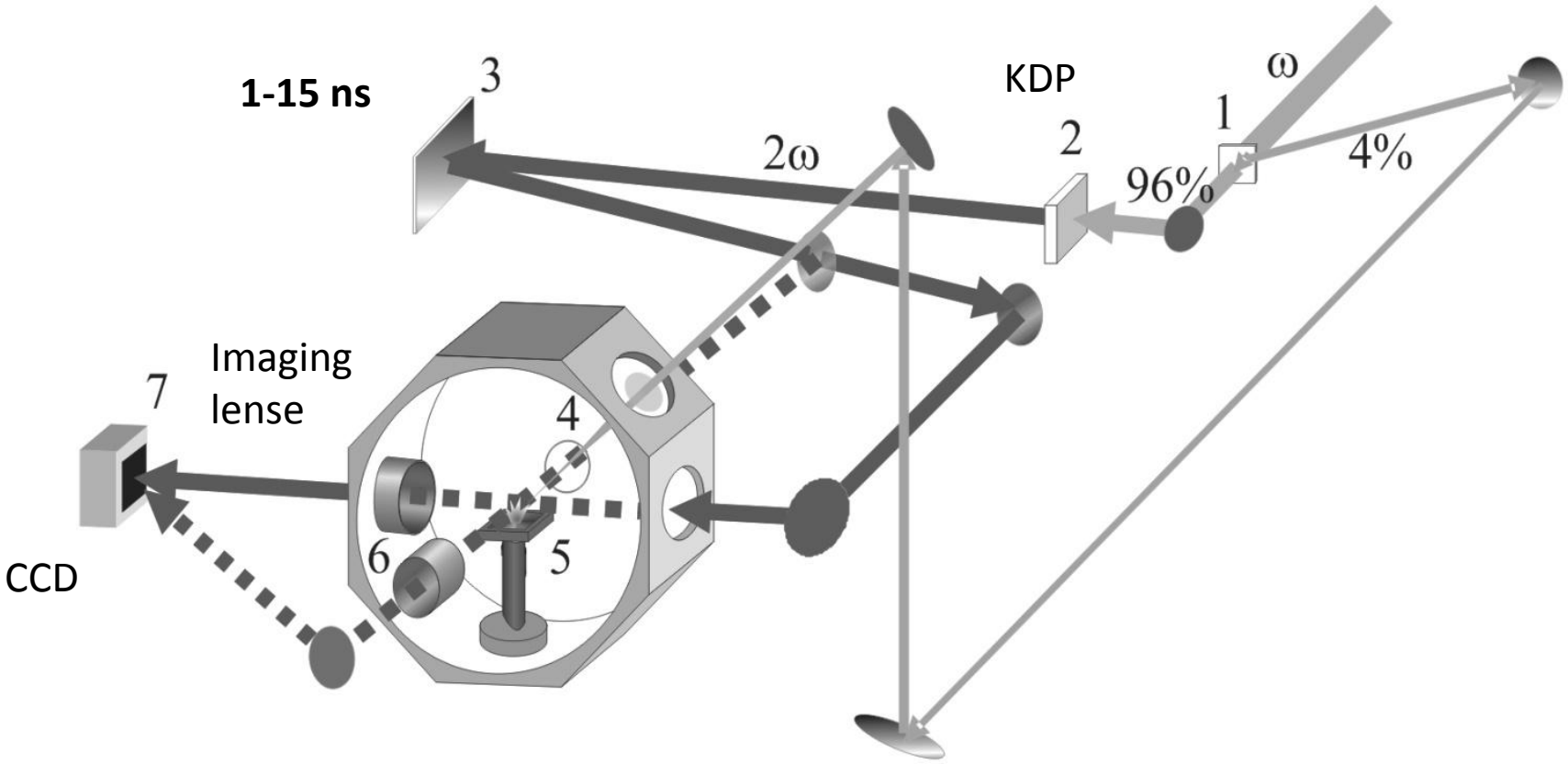
X-ray yield nanosecond contrast dependence ("low" intensity, MSU)

10^{17} W/cm^2



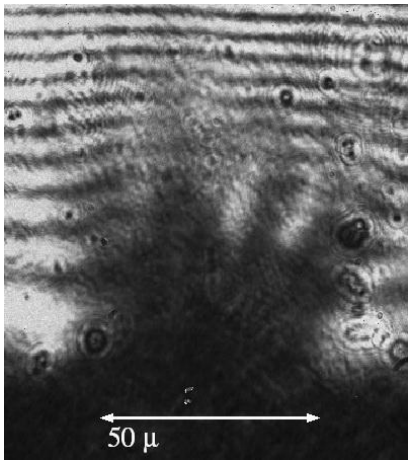


Plasma shadowgraphy

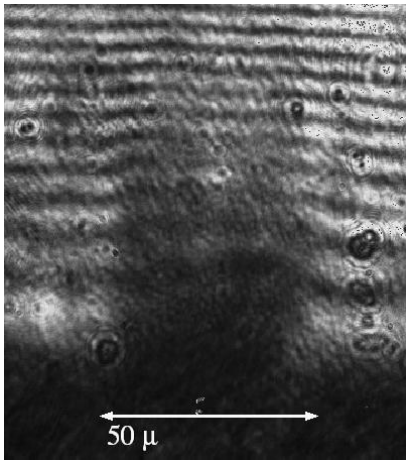


Liquid metal jet formation

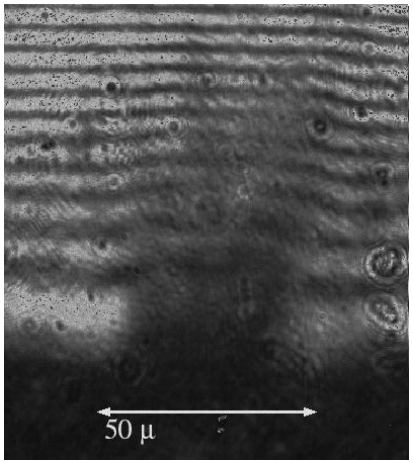
10^{16} W/cm^2



$5x10^{15}$ W/cm^2



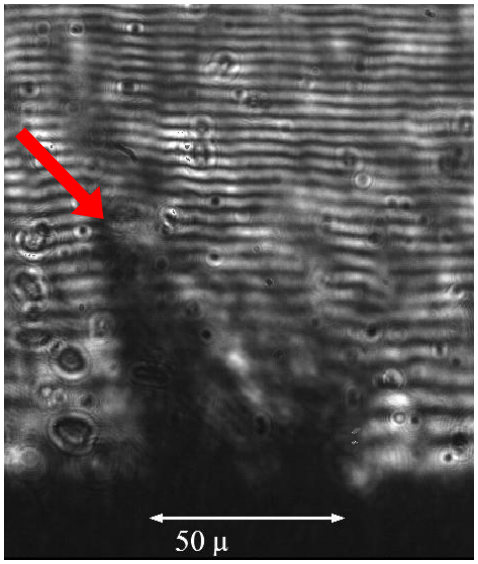
10^{15} W/cm^2



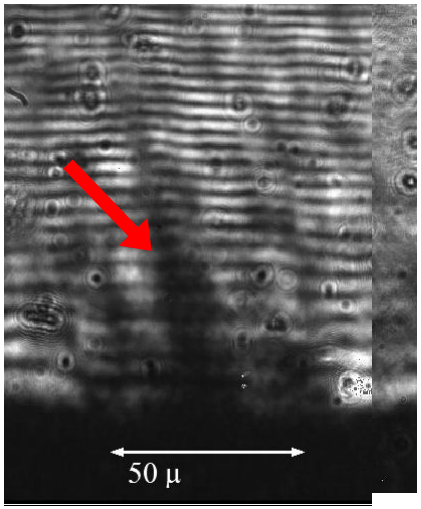
12 ns

Liquid metal jet formation

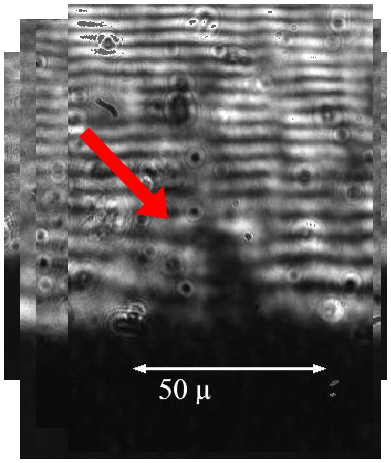
10^{16} W/cm^2



$5x10^{15}$ W/cm^2



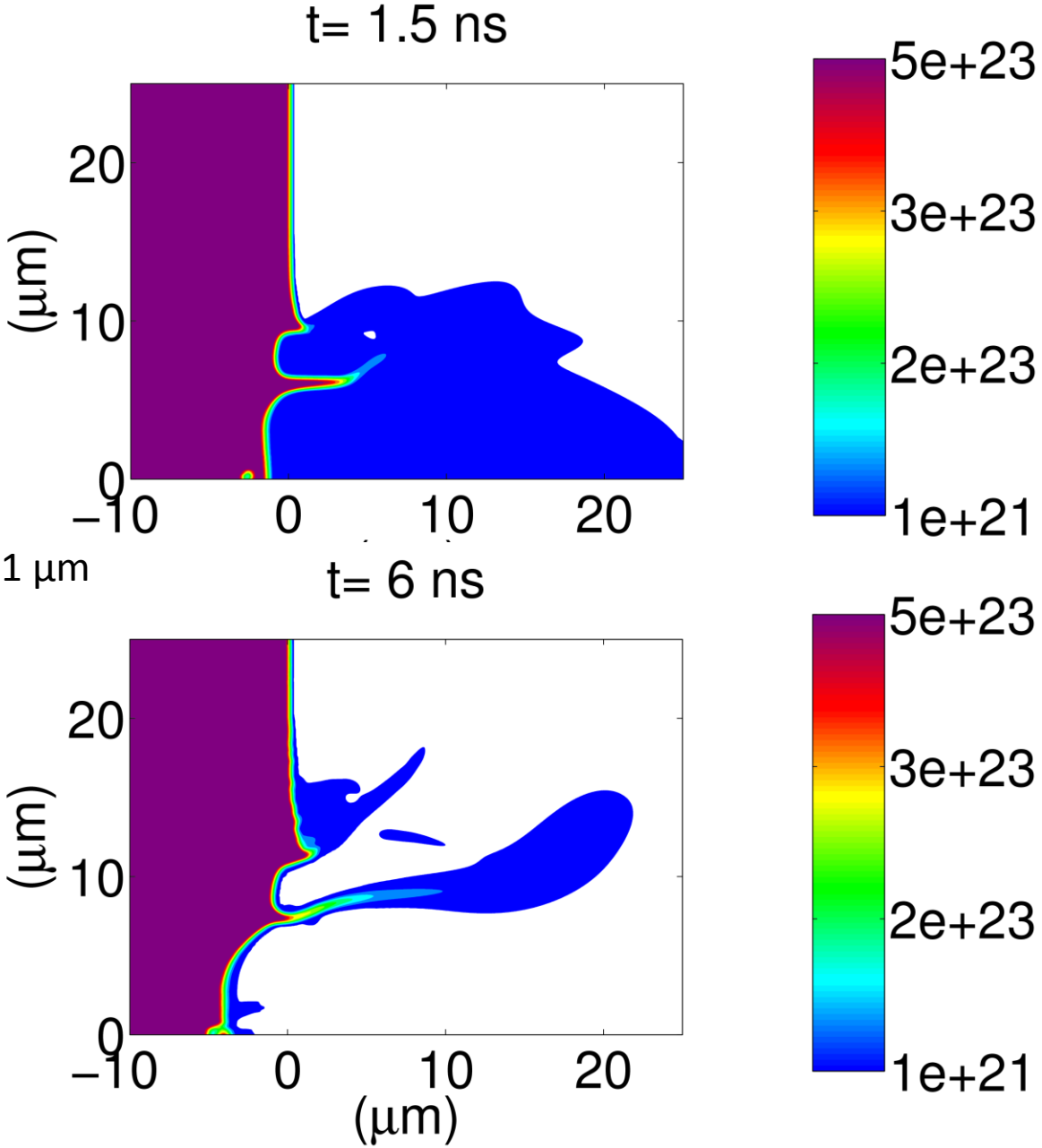
10^{15} W/cm^2



100 ns

2D CHIC hydrodynamic simulation

liquid aluminum
Central spot:
14 J/cm^2 in 4 µm s
Outer ring:
7.5 µm radius, width of 1 µm

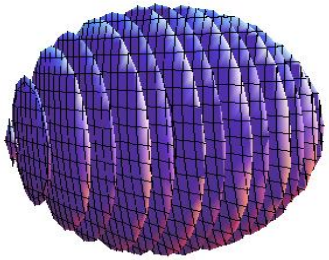


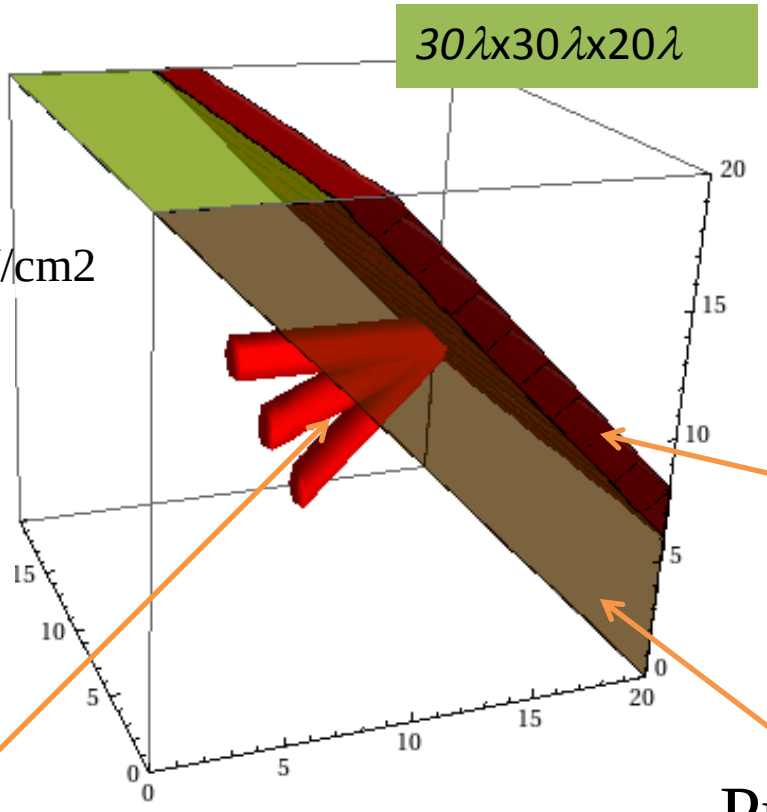
Electron acceleration along jets

3D3V Mandor PIC code http://mandor.ilc.edu.ru/mandor3

Laser pulse

- Duration 50 fs
- Focal spot 3 um
- intensity 5x1016-1018 W/cm2





Target:

-Proton + electrons
-Density 1022 cm -3
-thickness 1 um

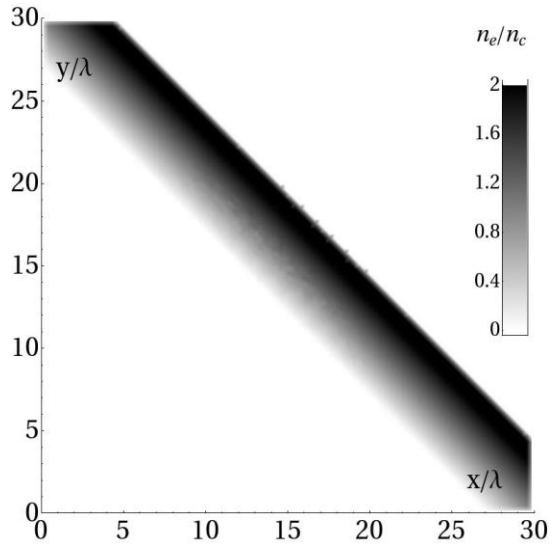
Jet:

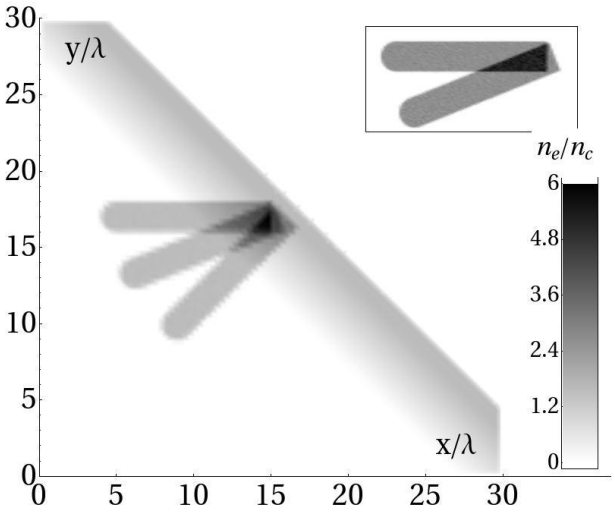
-Protons + electrons
- Density 1022 cm -3
- Jet length 5 um
- Jet diameter 0.5 um

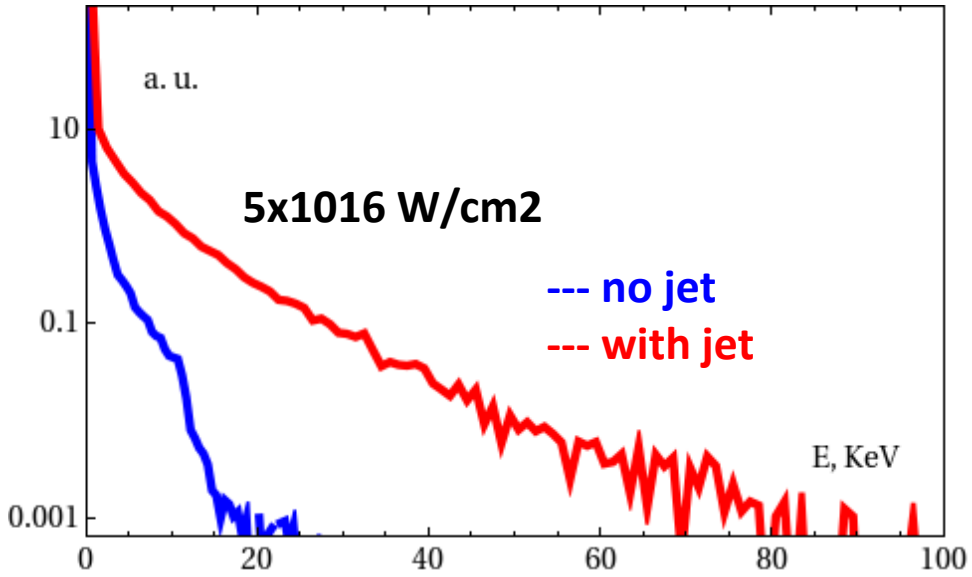
Preplasma:

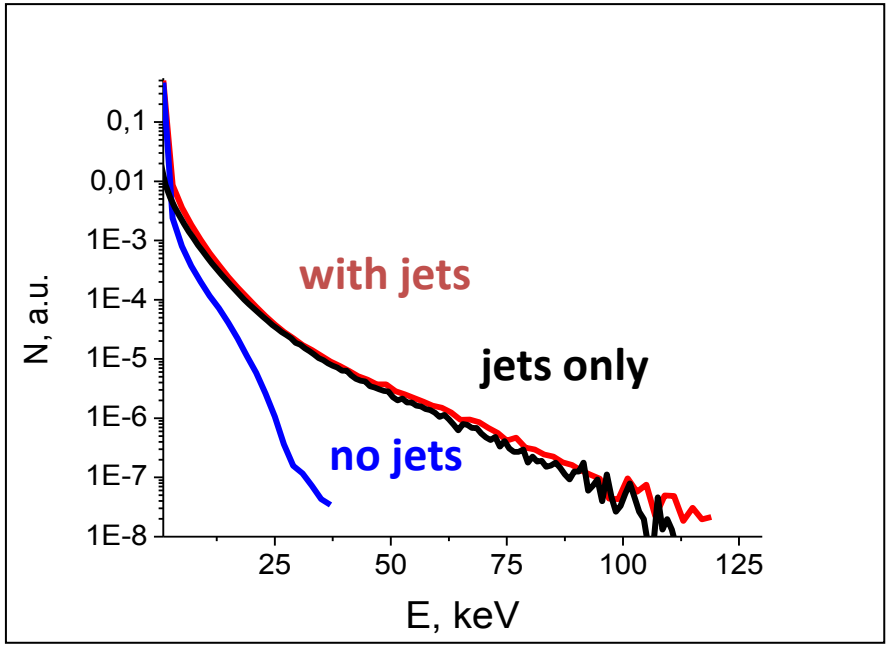
-Proton+electrons
-Density changes
from 0 to 1.2x1021 cm-3
-Thickness 4 um

Electron spectra from 3D3P modeling



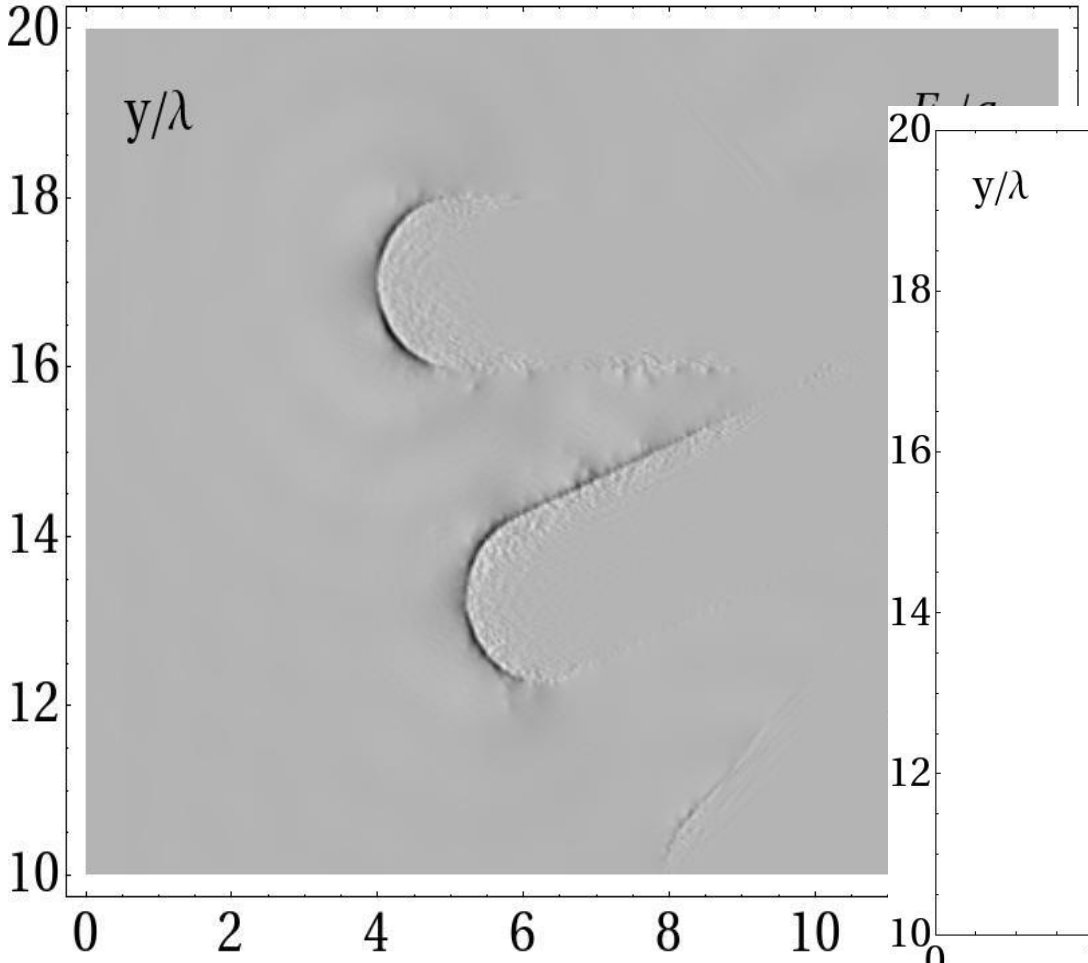




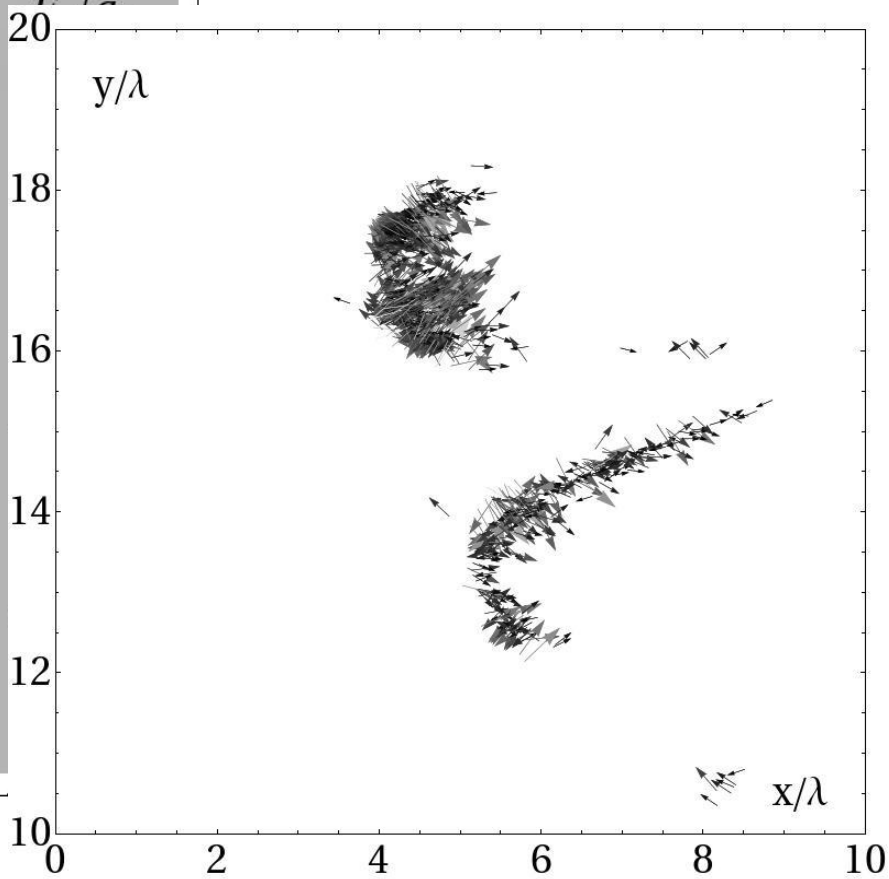


Electron acceleration with jets

Averaged longitudinal electric field

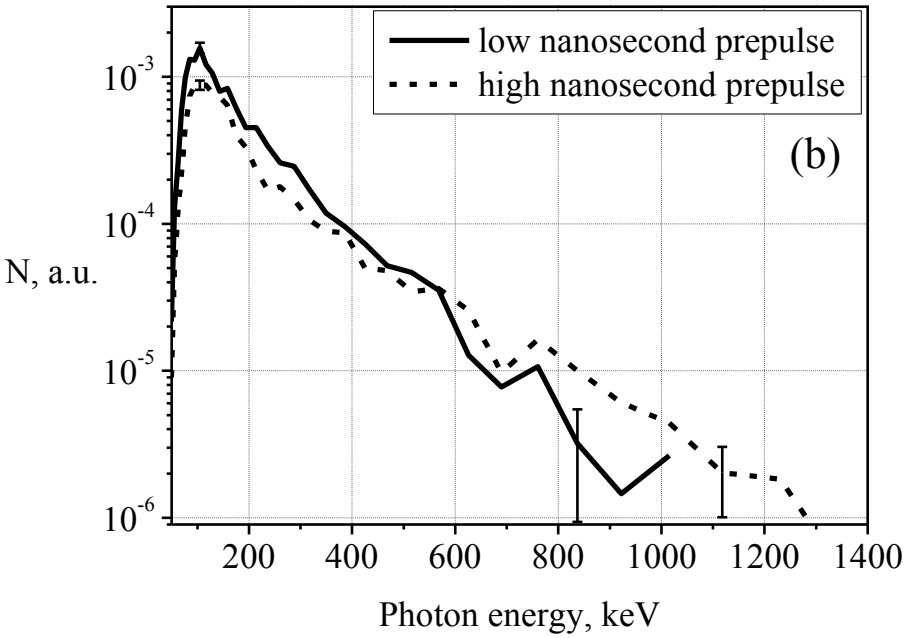


Hot electron distribution

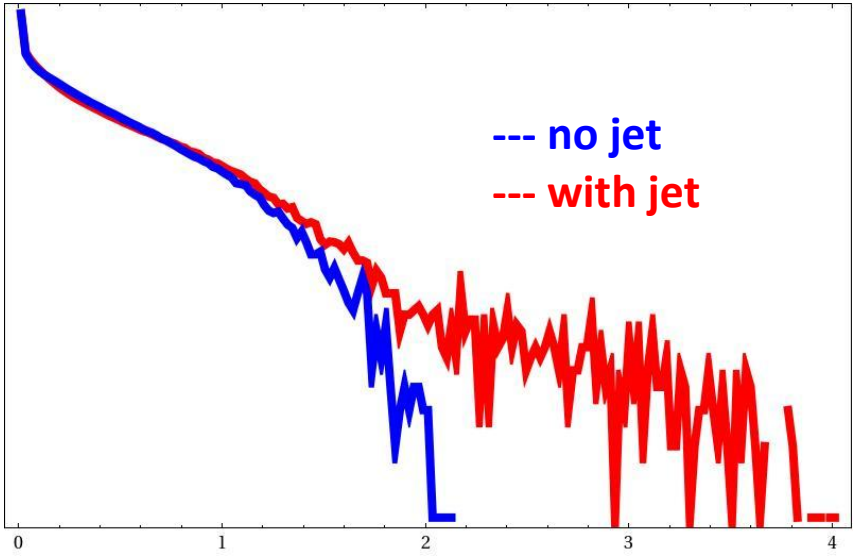


Hard X-ray yield at 2×10^{18} W/cm^2 intensity

Experiment



2D PIC



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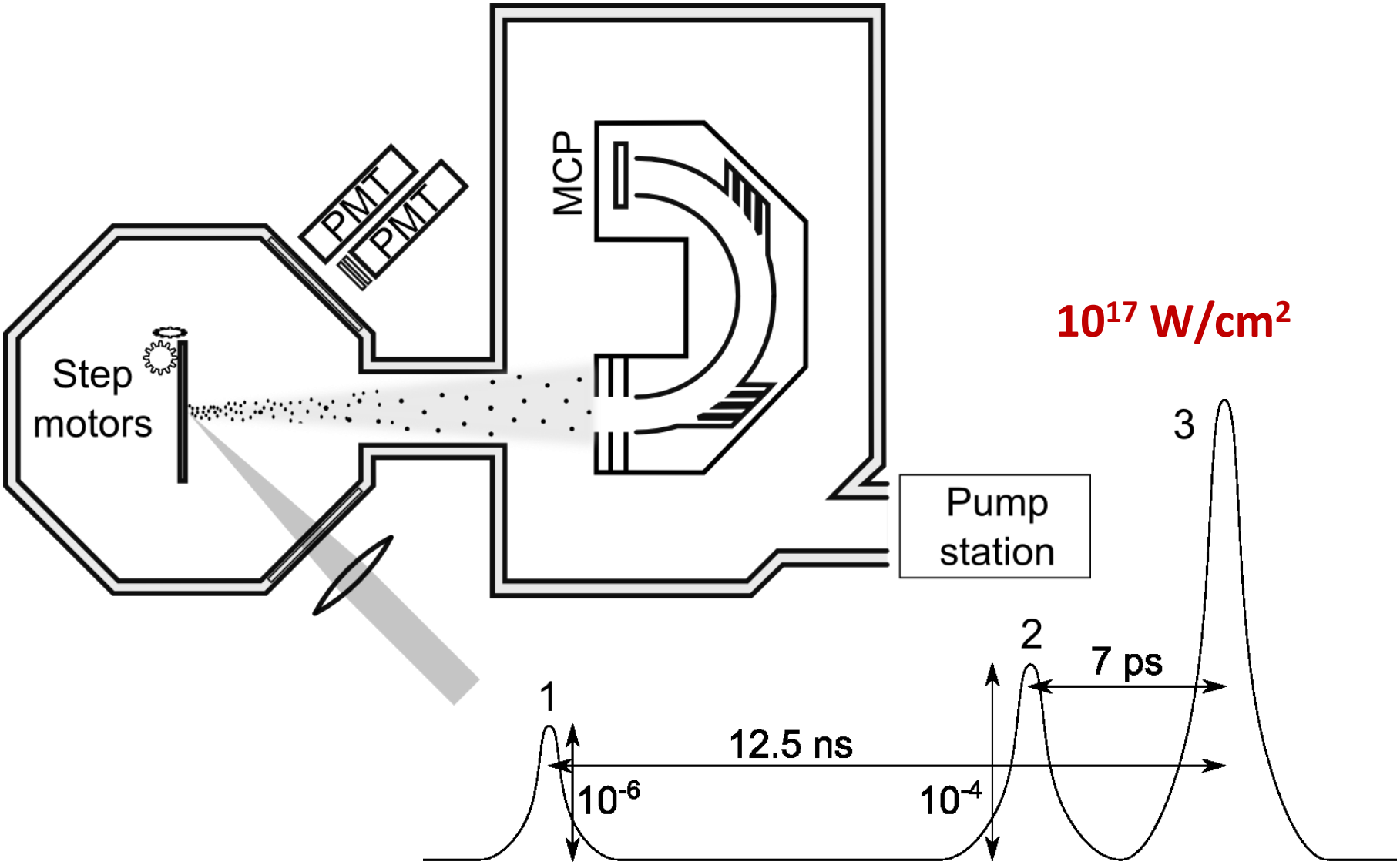
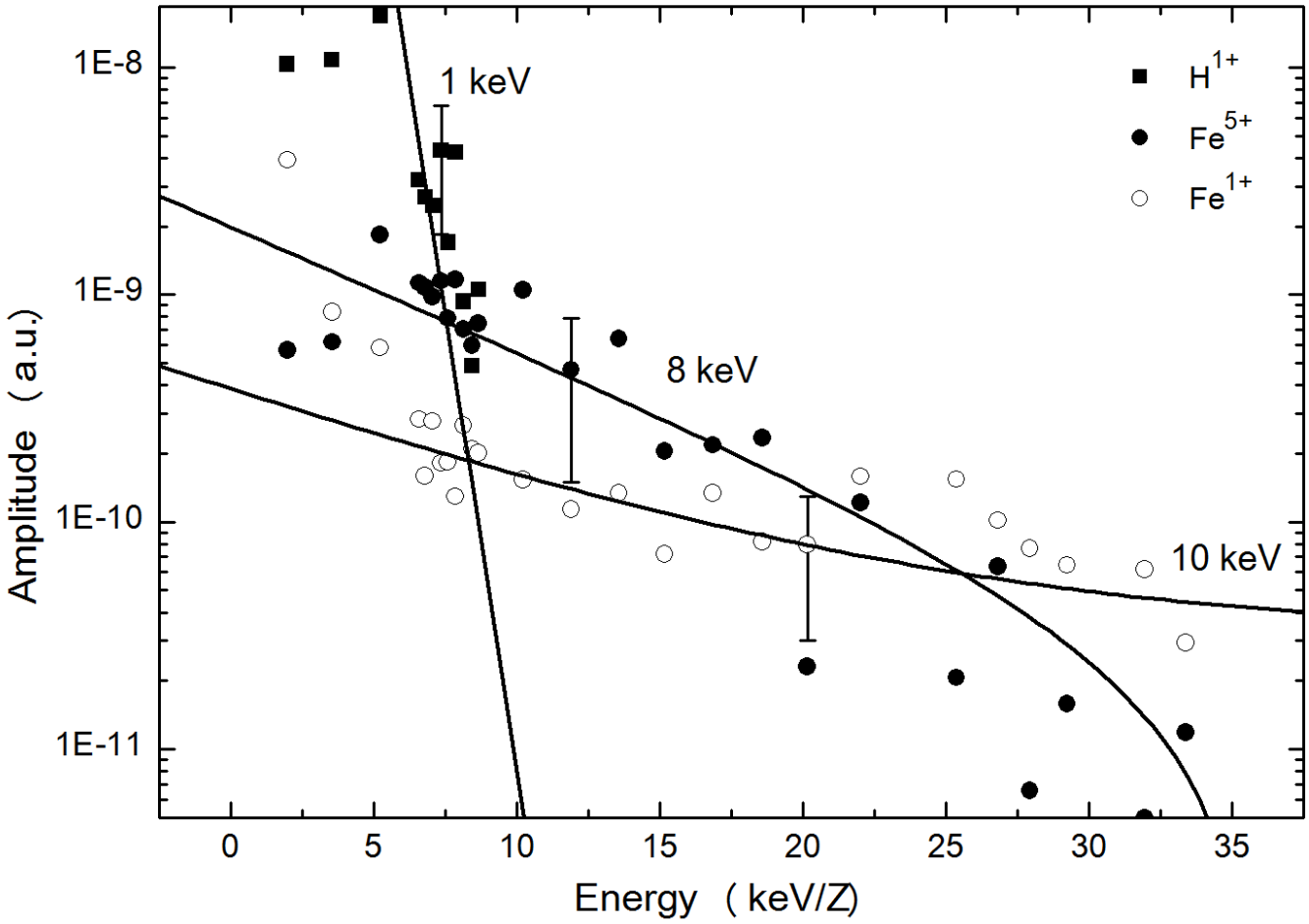
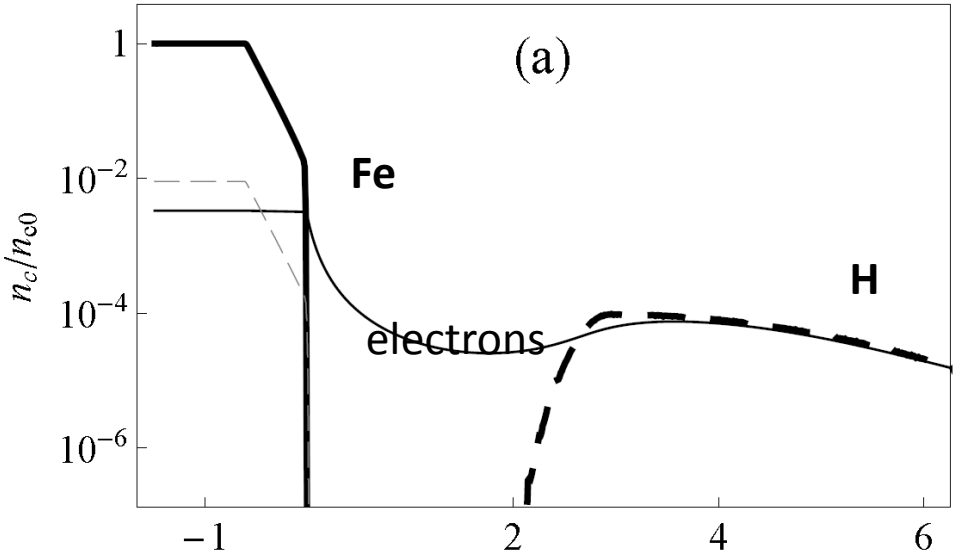
Experimental set up

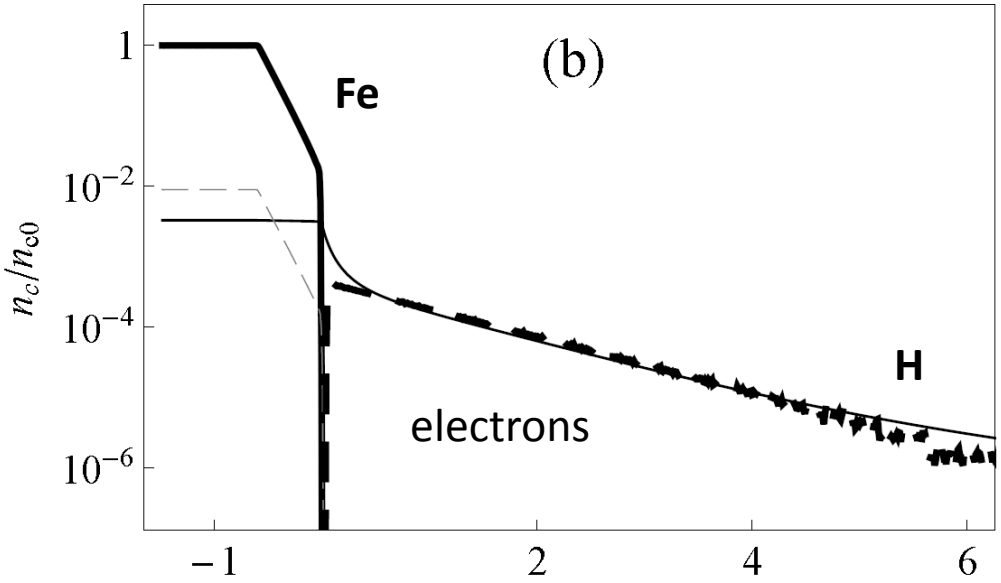


Ion spectra


1E-8
1E-9
1E-10
1E-11
Amplitude (a.u.)
0
5
10
15
20
25
30
35
Energy (keV/Z)
1 keV
8 keV
10 keV
H1+
Fe5+
Fe1+

1D Boltzmann-Vlasov-Poisson model





T_e=200 eV, T_h=10 keV

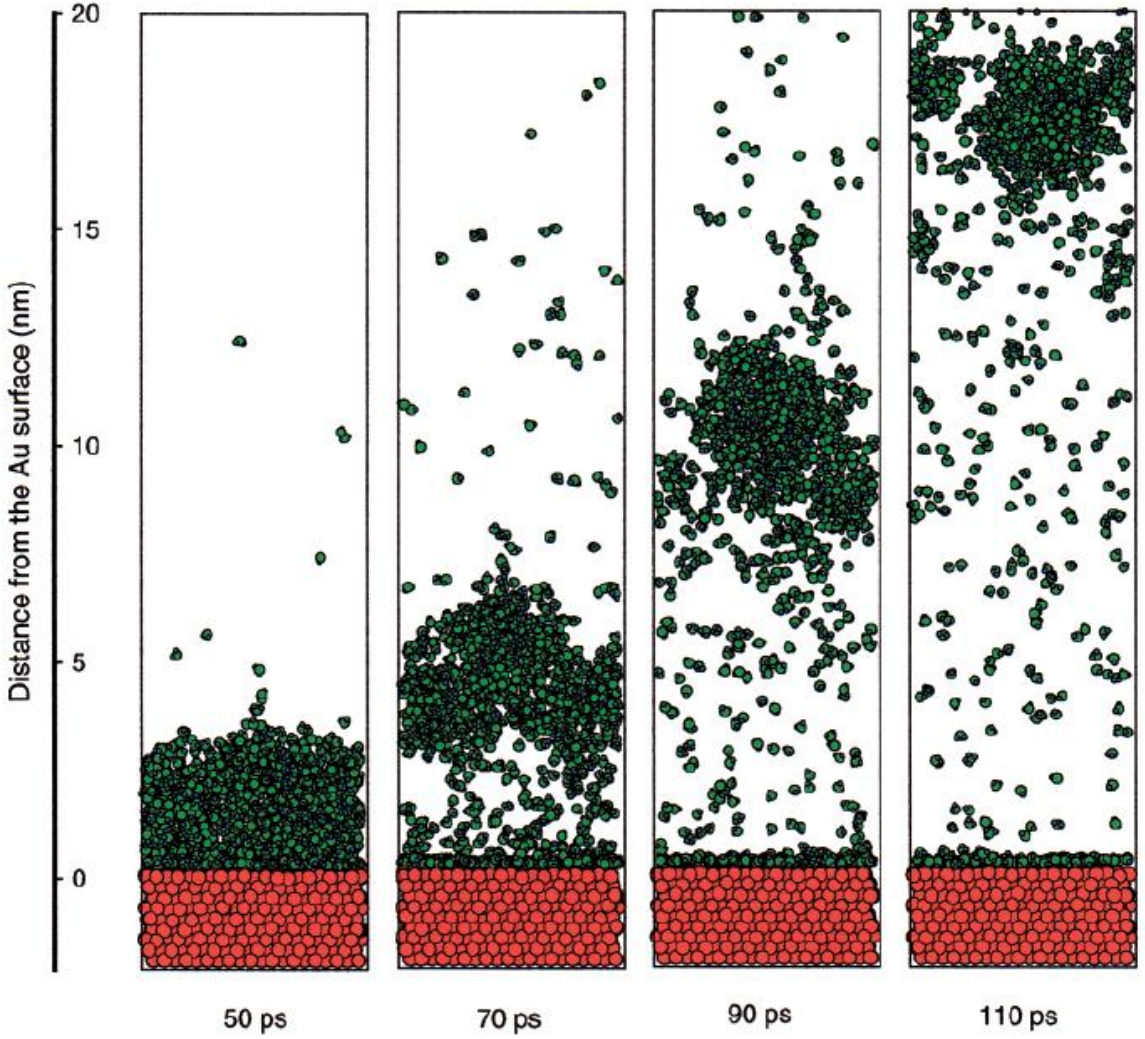
N_e=3x10^{23} cm^{-3}, N_h= 10^{20} cm^{-3}

900 K due to pre-pulse heating

Surface heating and water layer explosive evaporation

1000 K

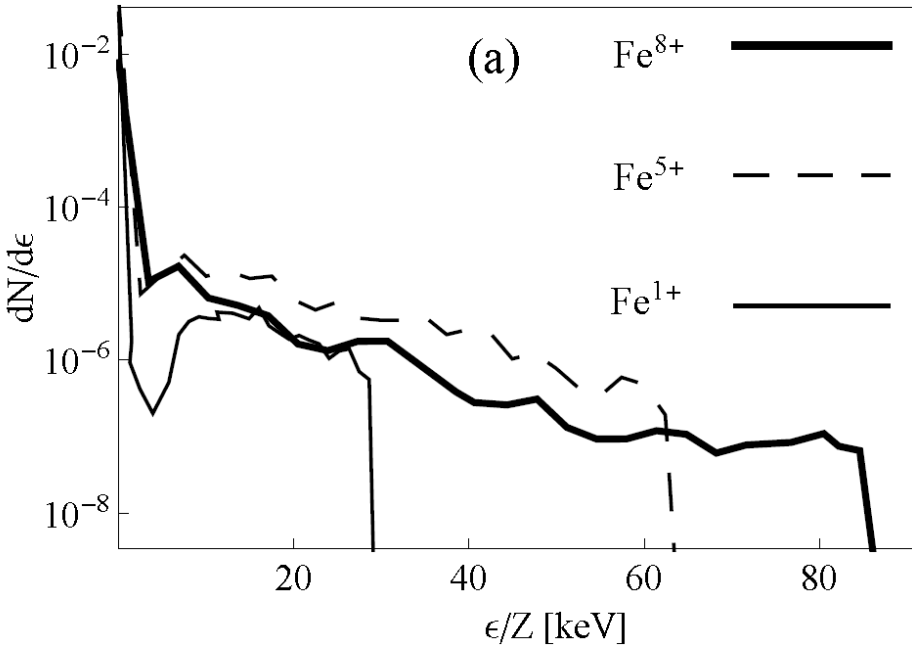
H_2O/Au

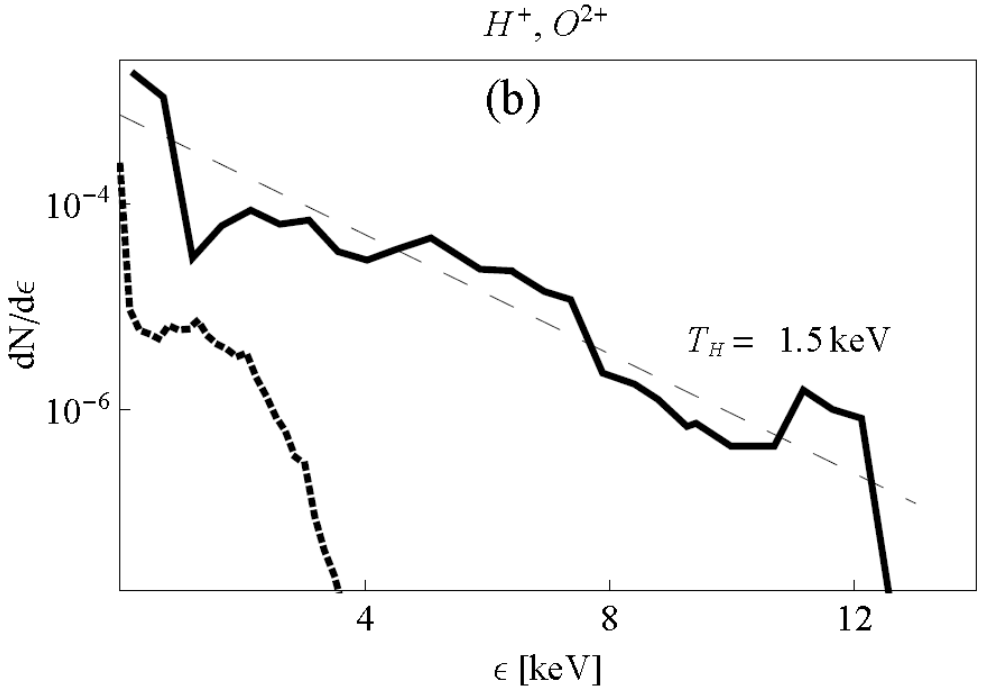


J. Phys. Chem. A **2001,** *105,* 2748−2755

Nuclear Instruments and Methods in Physics Research B 180 (2001) 105–111

Ion spectra of different species

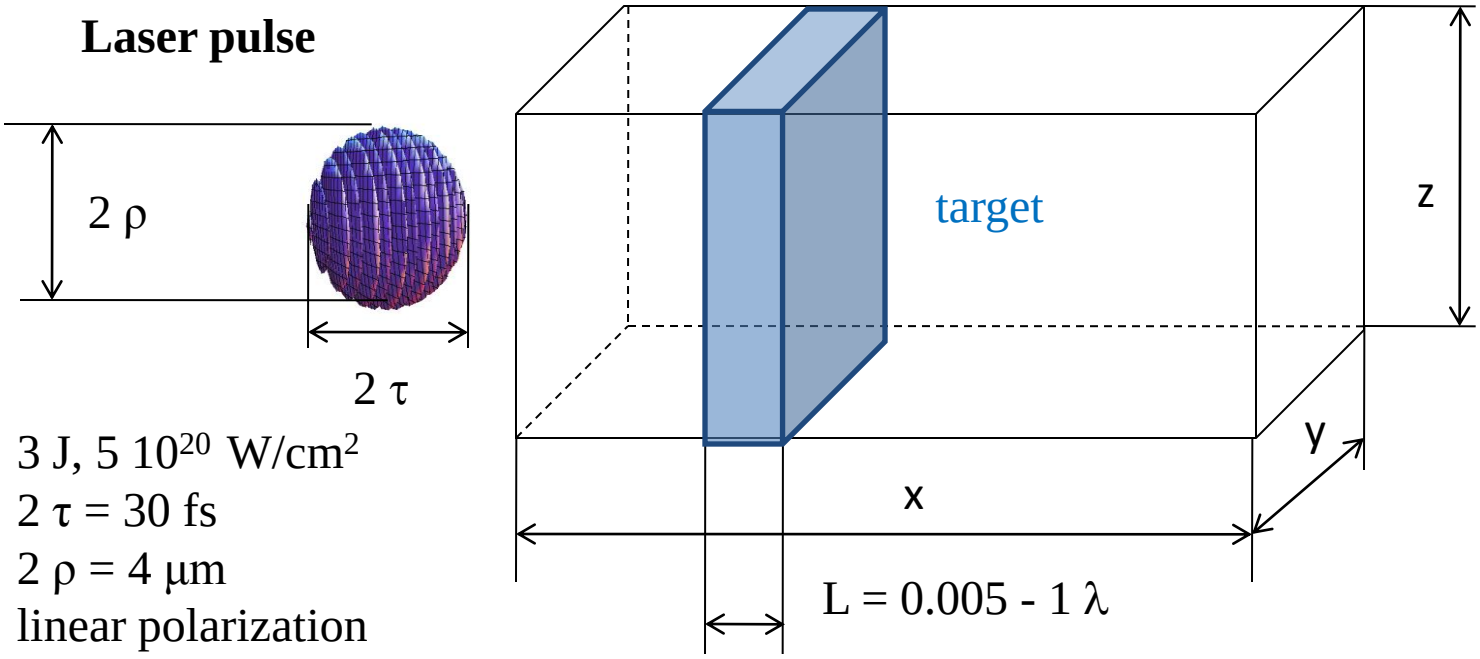




Outline

- Pre-plasma impact onto fast electron generation at high intensities – solid targets
- Pre-plasma impact onto fast electron generation at high intensities – liquid metal targets
- Pre-pulse effect onto heavy ion acceleration
- Proton acceleration at ultrahigh intensities: thin foil thickness optimization & microstructuring impact

3D PIC code for simulation of laser-plasma interaction



3 J, 5 10^{20} W/cm^2
2 τ = 30 fs
2 ρ = 4 μm
linear polarization

Target
CH_2 foil
(n_e=200 n_c)

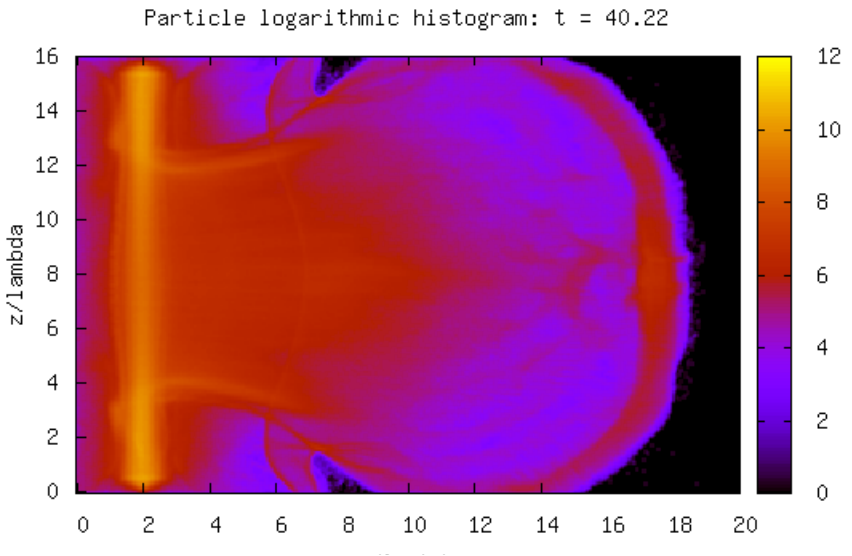
- electrons
- heavy ions
- light ions (protons)

$x \times y \times z = 20\ \lambda \times 20\ \lambda \times 20\ \lambda$

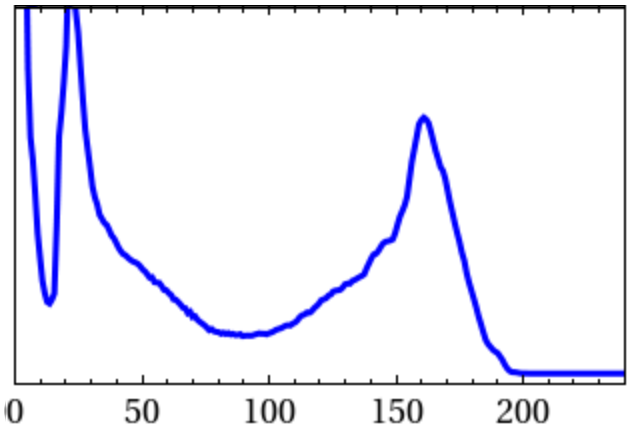
$\Delta x \times \Delta y \times \Delta z = \lambda/100 \times \lambda/20 \times \lambda/20$

- different target forms (foil, disk, spherical clusters)
- pre-plasma modeling with linear or exponential density profiles

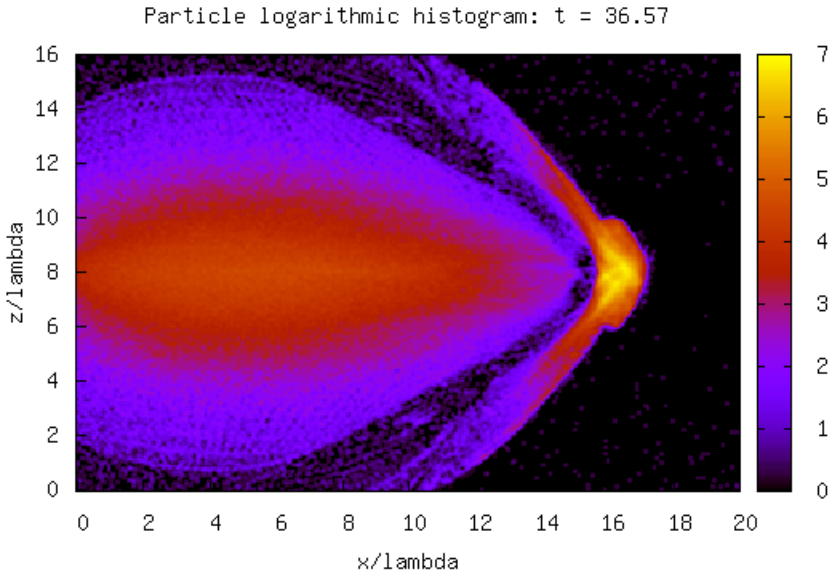
Proton acceleration from mass-limited target

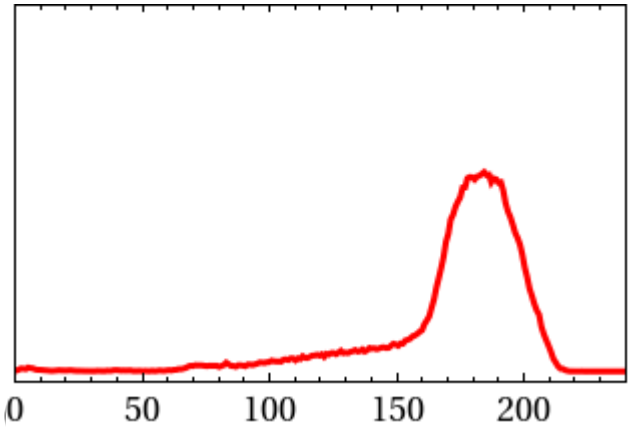


Proton energy spectrum



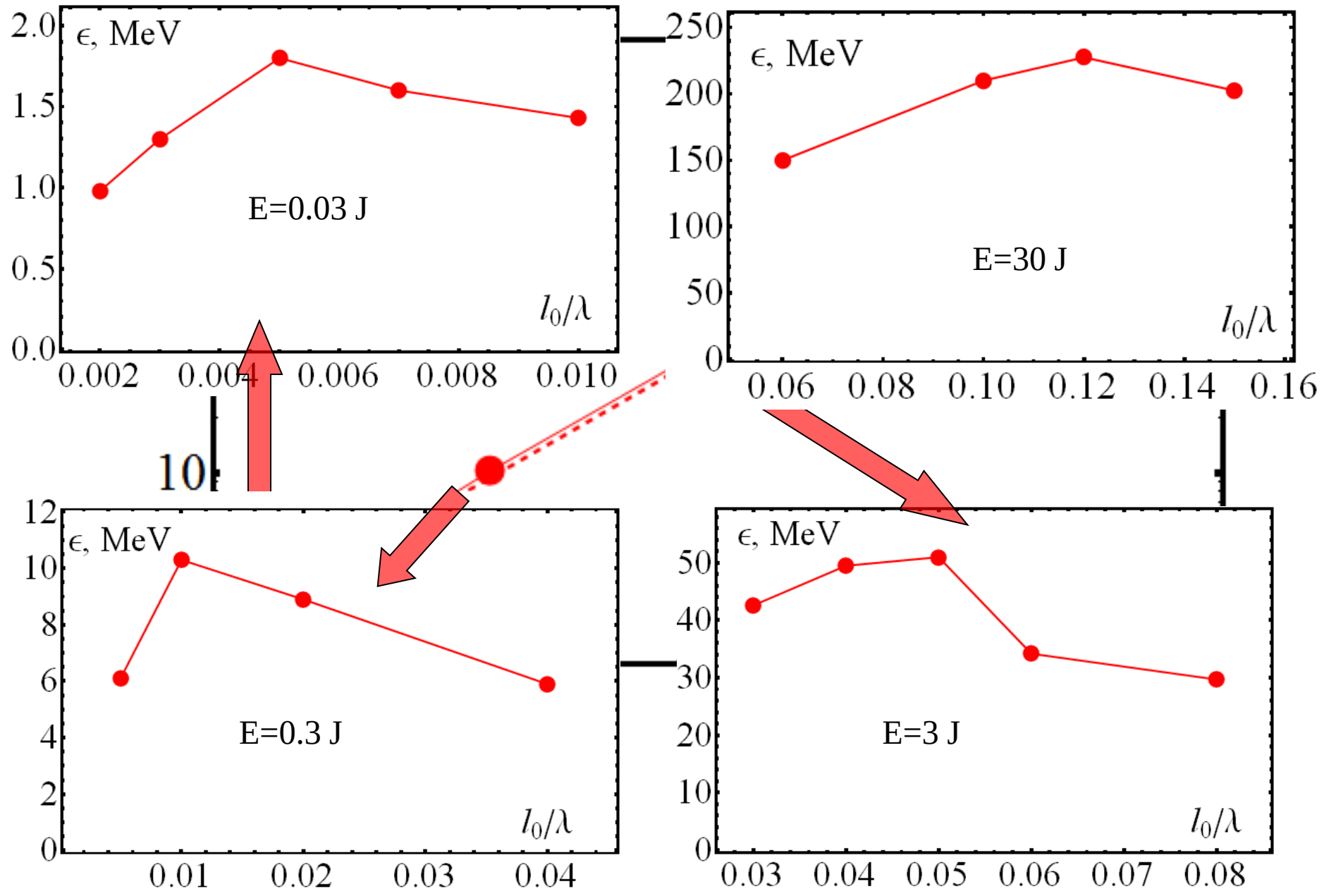
Proton energy MeV



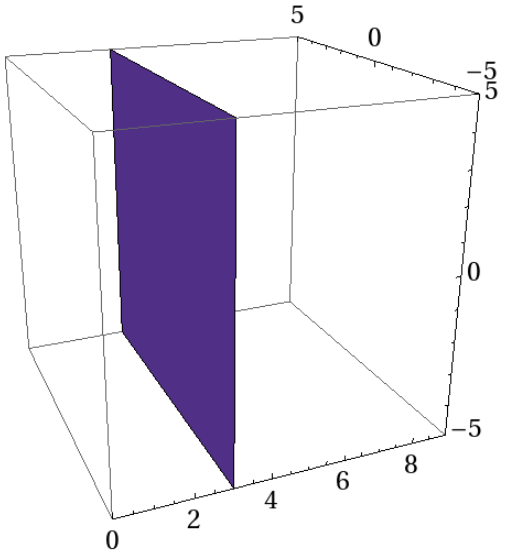


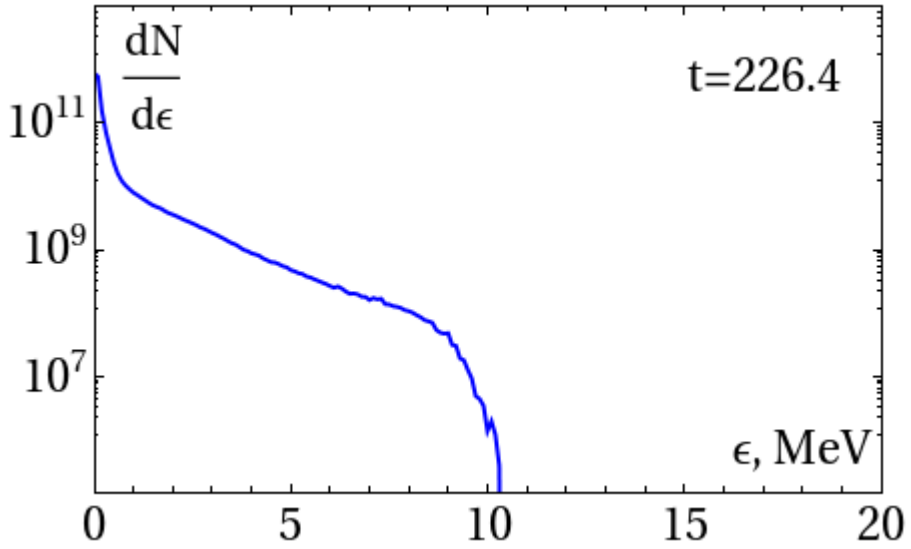
Proton energy MeV

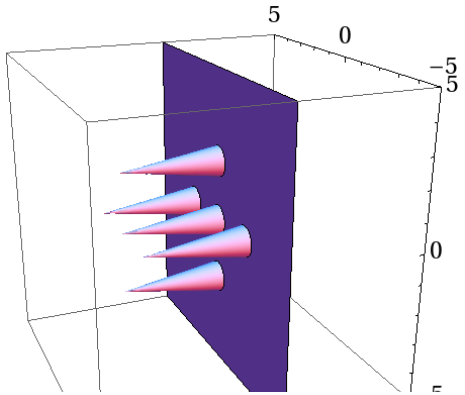
Proton acceleration from ultra-thin foils



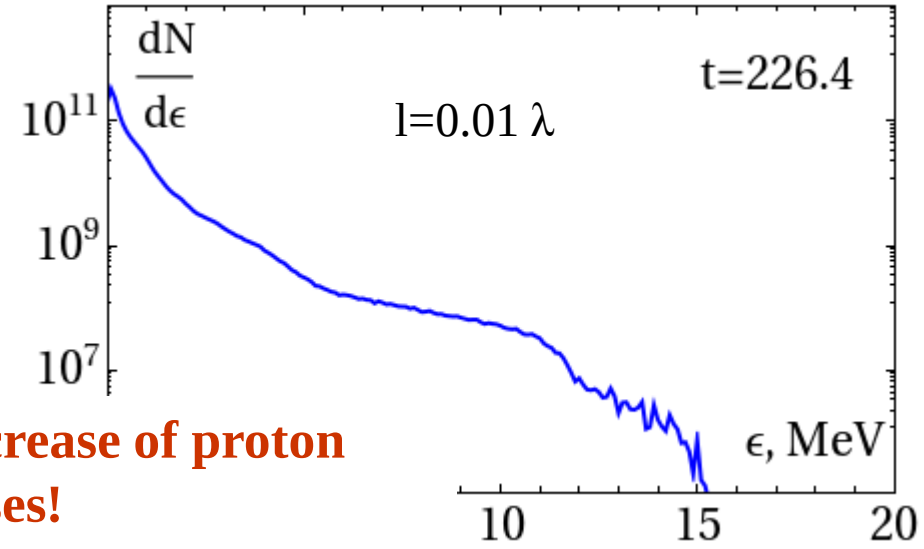
Proton acceleration from structured target at 5×10^{19} W/cm^2





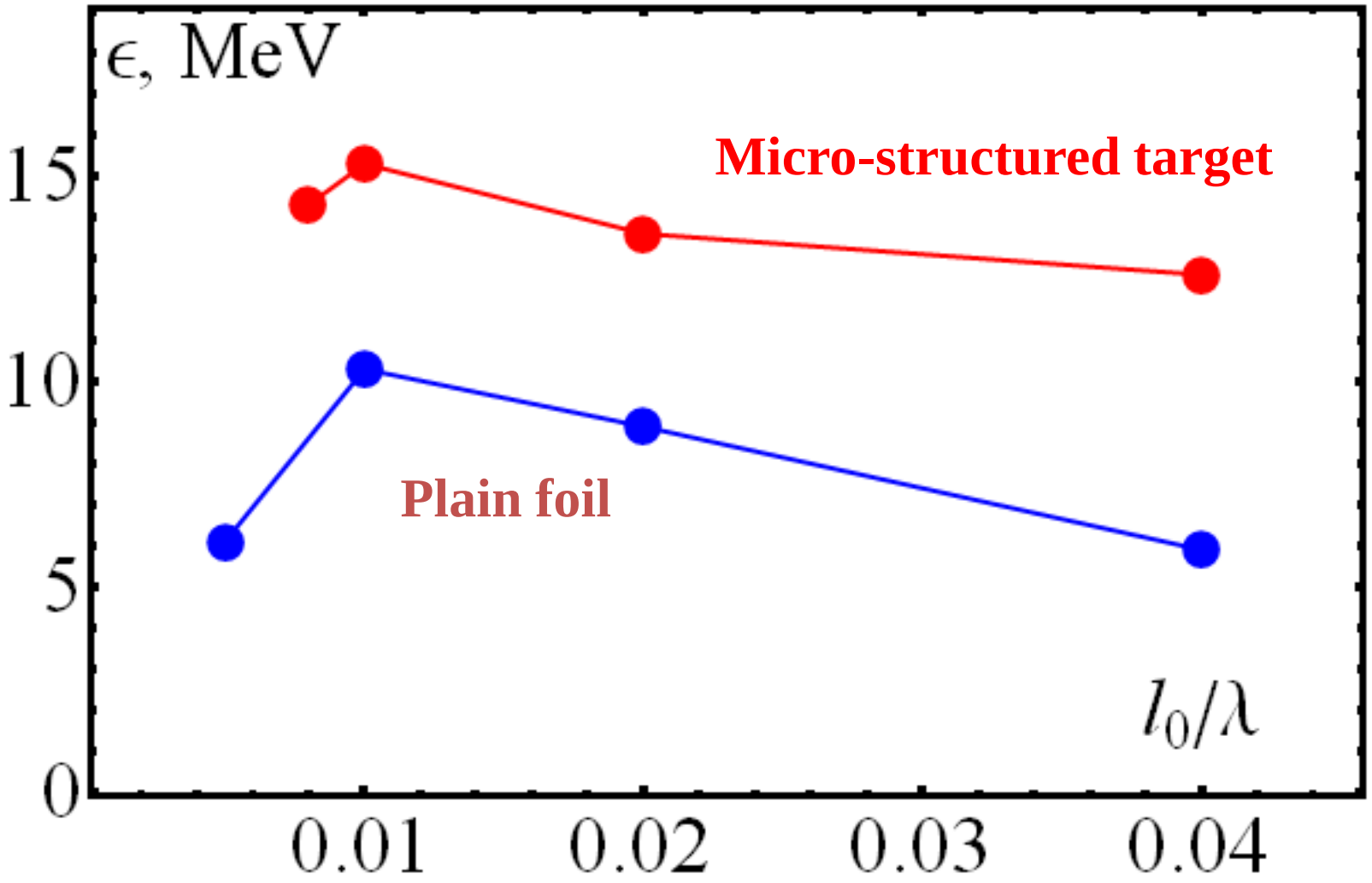


L=3 μm
L/d=6/5



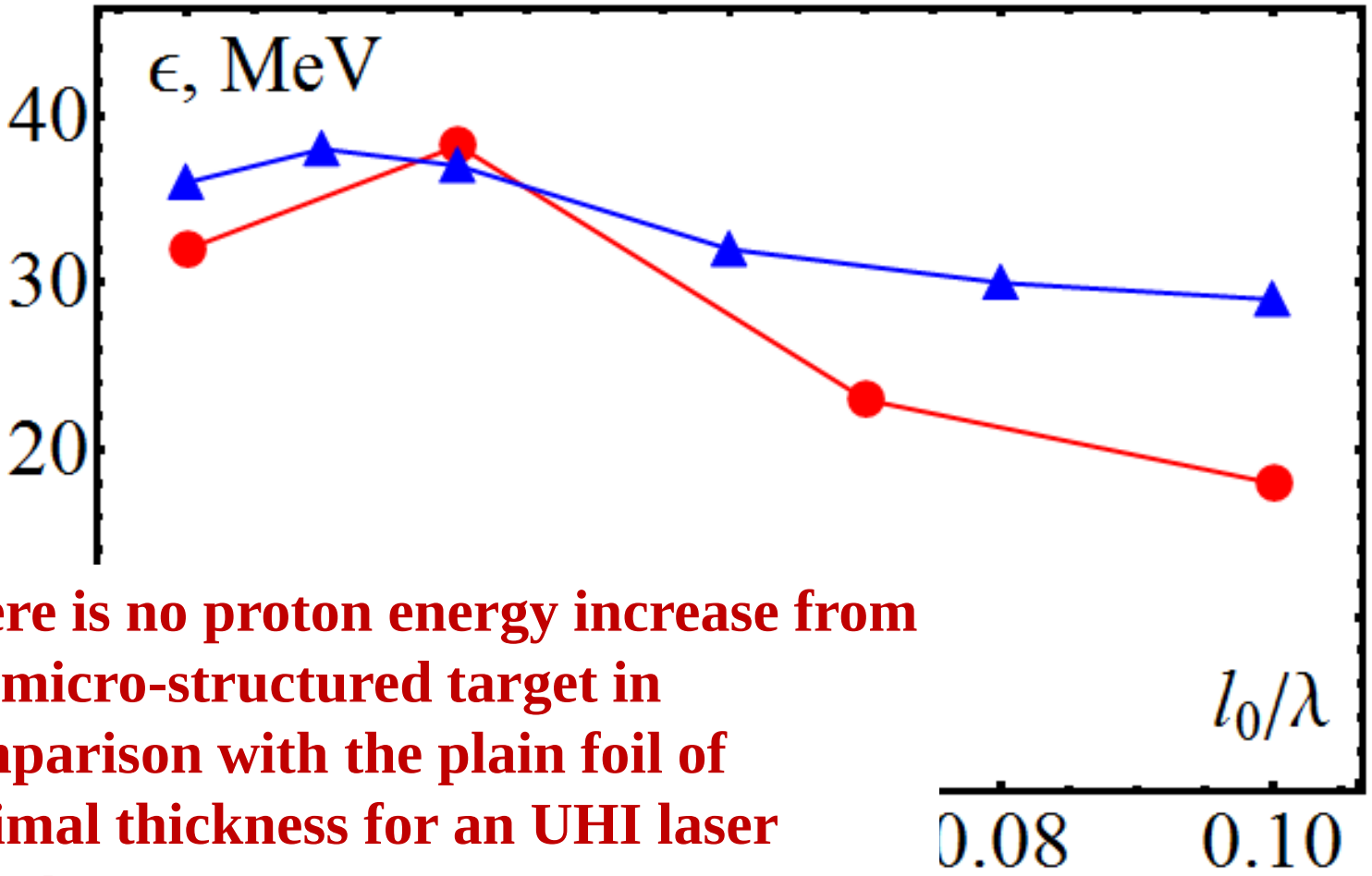
The structured surface results in increase of proton energy for relatively weak laser pulses!

Proton acceleration at 5×10^{19} W/cm^2



L=3 μm
L/d=6/5

Micro-structured target at 2×10^{20} W/cm^2



There is no proton energy increase from the micro-structured target in comparison with the plain foil of optimal thickness for an UHI laser pulse!

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Thank you

for your attention!

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