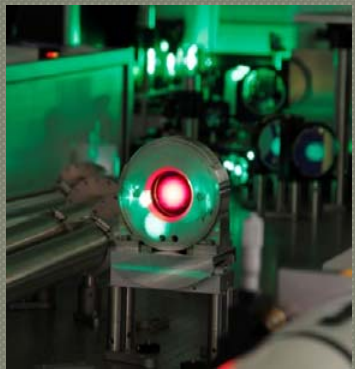
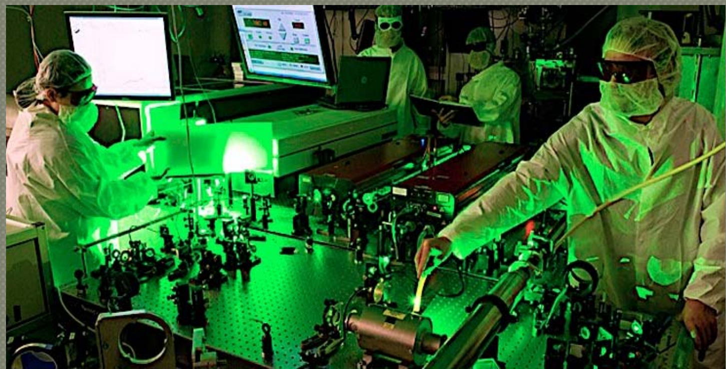
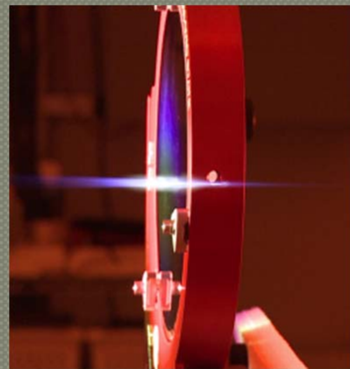
Modification of the energy and spatial spectra of relativistic LPI electrons by front-surface target structures







RR Freeman
Scarlet Laser Facility
The Ohio State University
hedp.osu.edu

National Nuclear Security Administration

Ohio Supercomputer Center
Empower. Partner. Lead.

Acknowledgements

S. Jiang, L. L. Ji, J. Snyder, K. M. George, D. W. Schumacher, K. U. Akli

A. G. Krygier

H. Audesirk, N. S. Lewis

A. Pukhov

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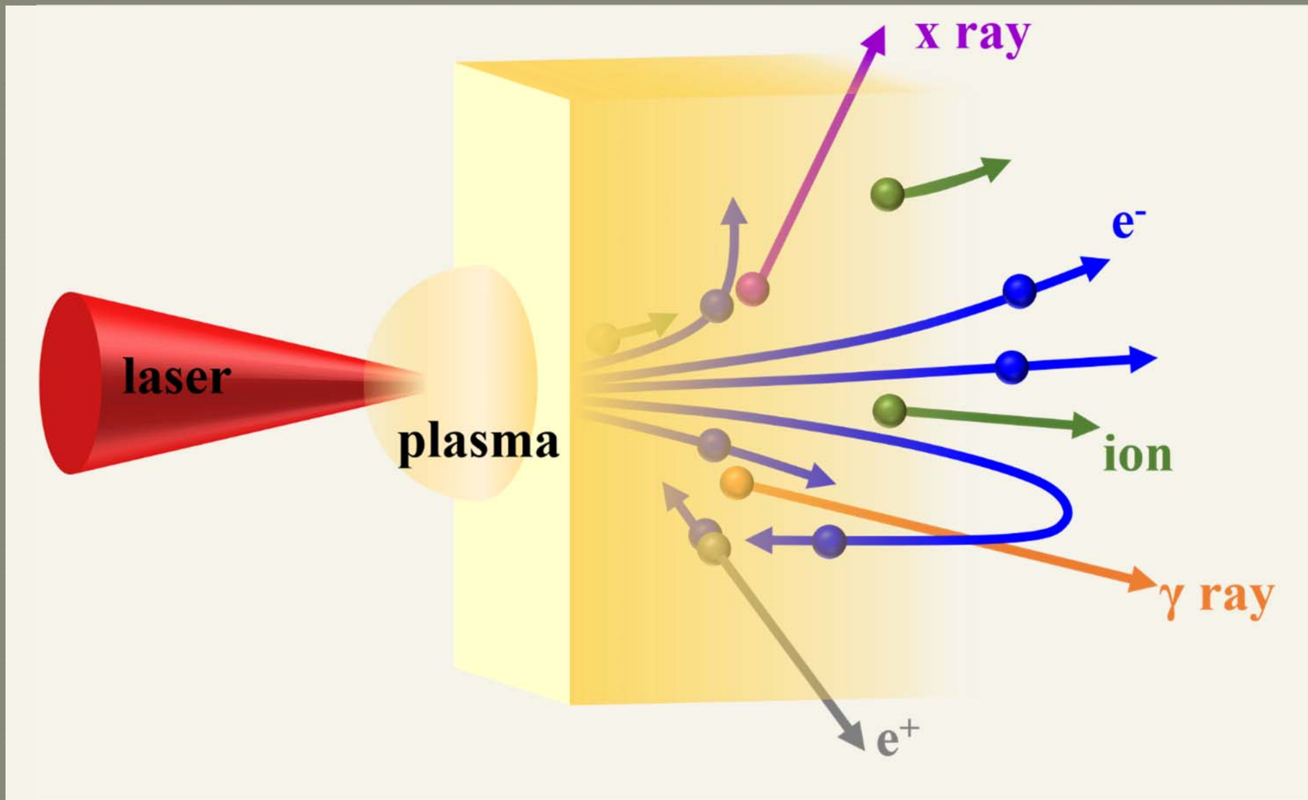
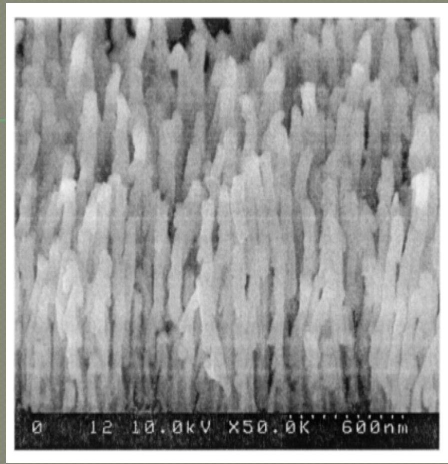
Short-pulse lasers produce e⁻/e+, fast ions, X-rays, and γ-rays



Can the LPI be controlled?

Nano-structured "Velvet" Target



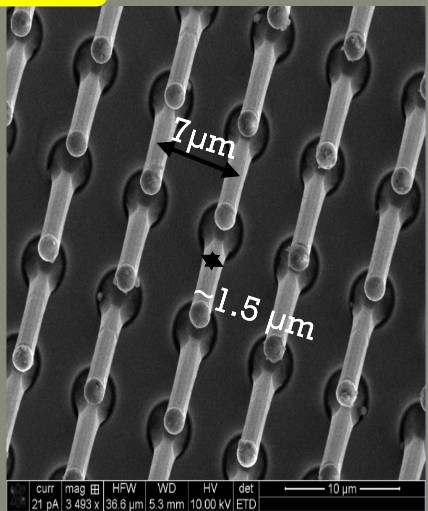
G. Kulcsár et al., Phys. Rev. Lett. 84, 5149 (2000)

Increase the interface to enhance absorption.

Random.

Uncontrollable.

Micro-cylinder Target



S. Jiang, A. Krygier et al., Phys. Rev. E 89, 013106

Well organized.

Adjustable.

Why 3D printed nano/micro-targets?

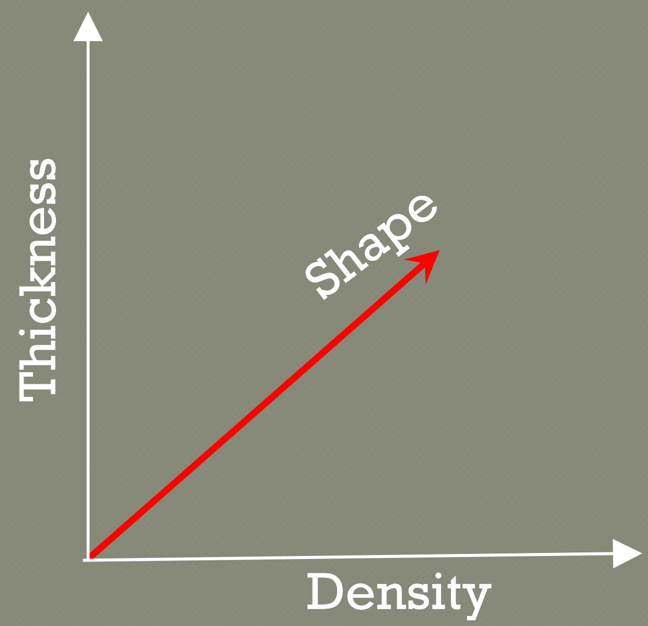
Nano/micro-structures can survive under Relativistic laser intensities.

- Femto-second pulse duration
- High contrast (10^{-9})

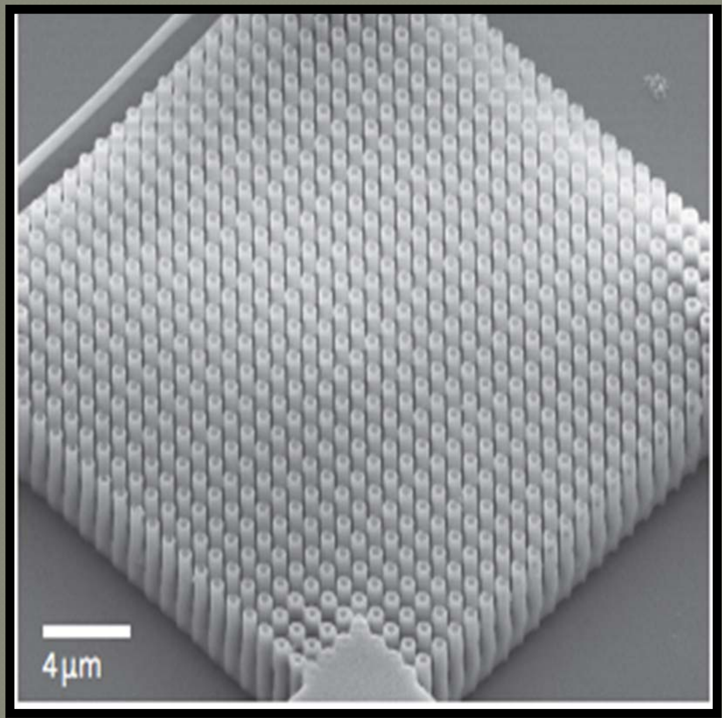
3D nano-printing technique

- Fine structures (200nm resolution)
- High repetition
- Full precise control

Another degree of freedom in LPI.

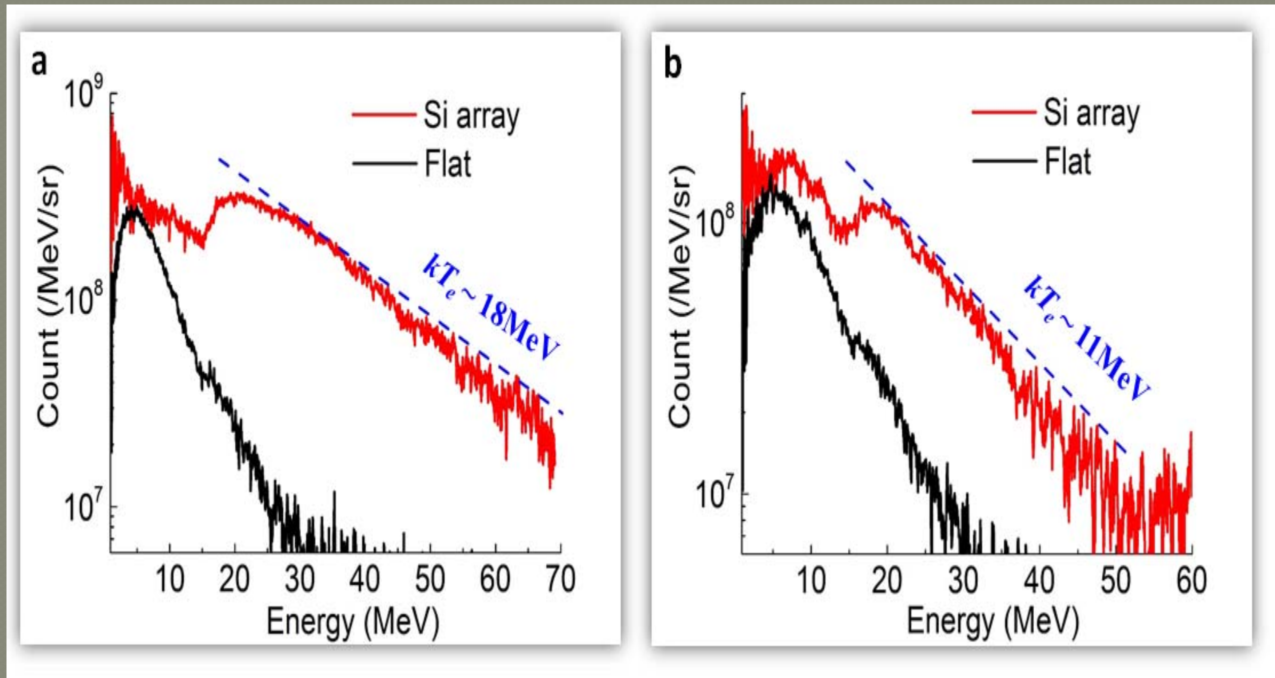


3D-printed micro-tube plasma (MTP) targets



Experiments

Flat



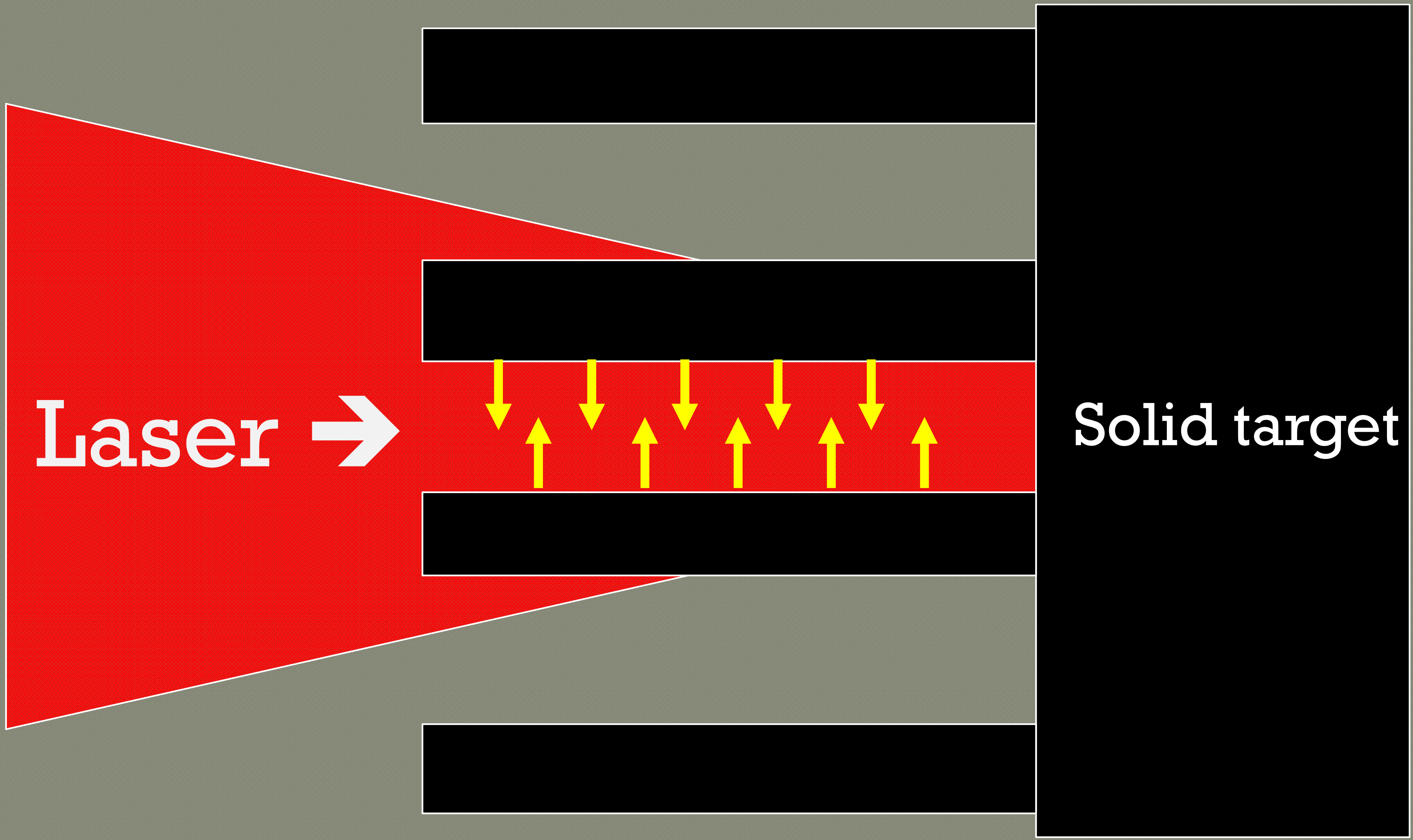
~ 5J on target

~ 40 fs pulse duration,

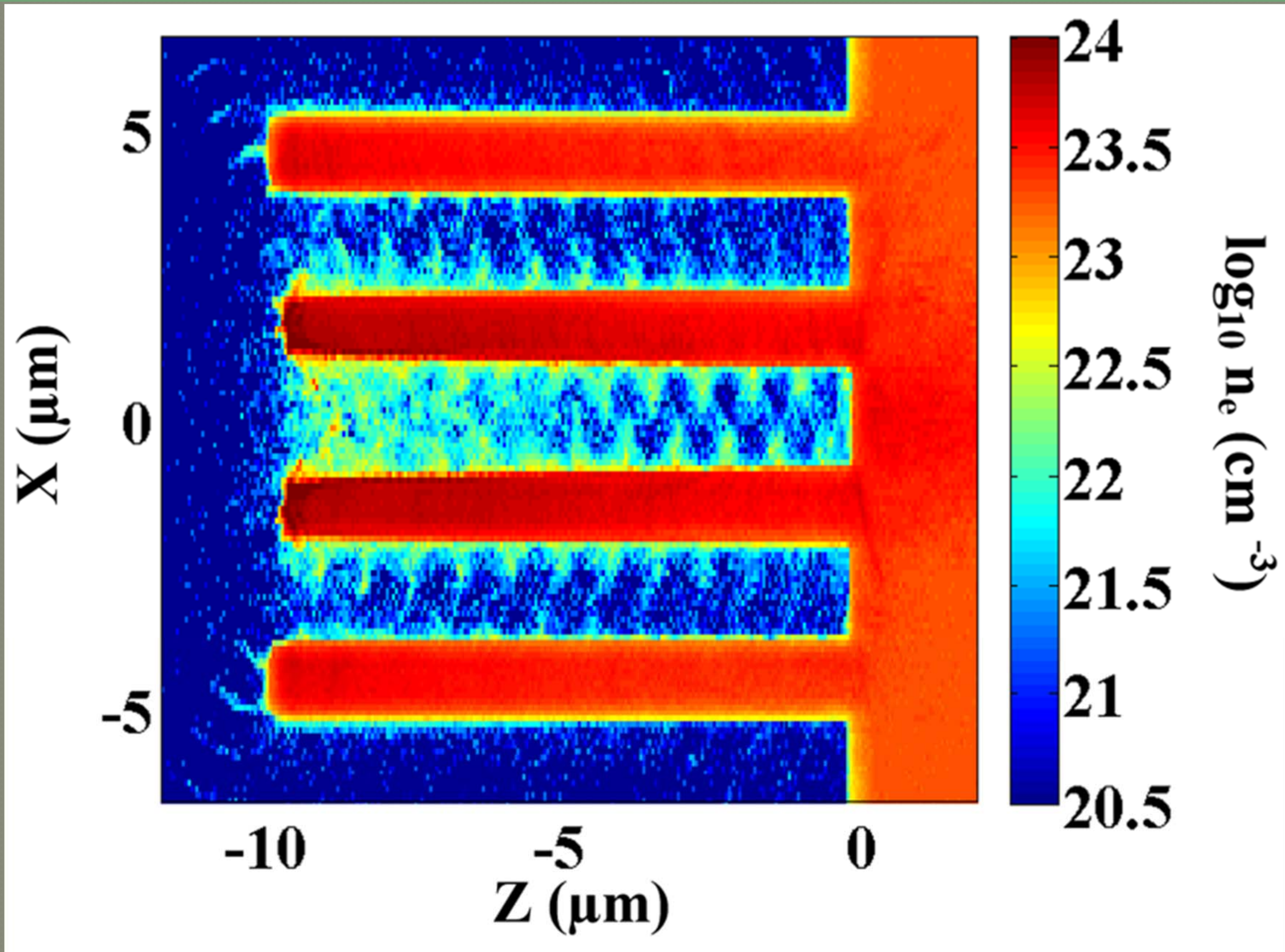
Intensity ~ 10^{21} W/cm^2

At least an order of magnitude enhancement for electrons with energies > 10 MeV

How do these targets work?



2D model illuminates 3D physics



PIC simulation (LSP and VLPL) details

Laser:

40 fs, 3.2 μm focus

$E = 15J \quad \lambda = 0.8\ \mu m$

$a_0 = 21$

(Scarlet conditions)

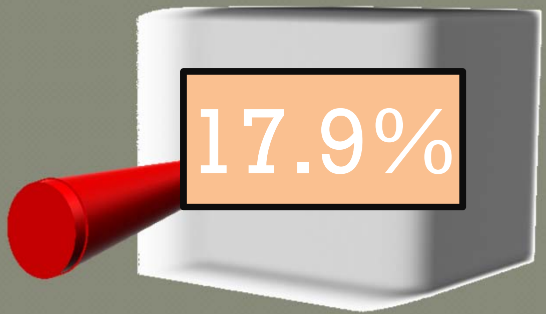
Simulation details:

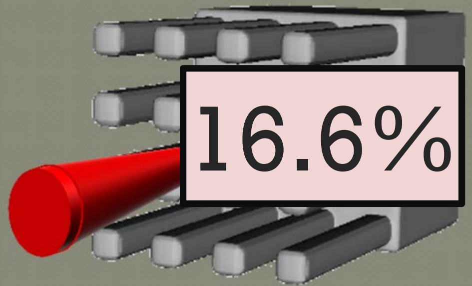
$\Delta x = \Delta y = 0.1\ \mu m$

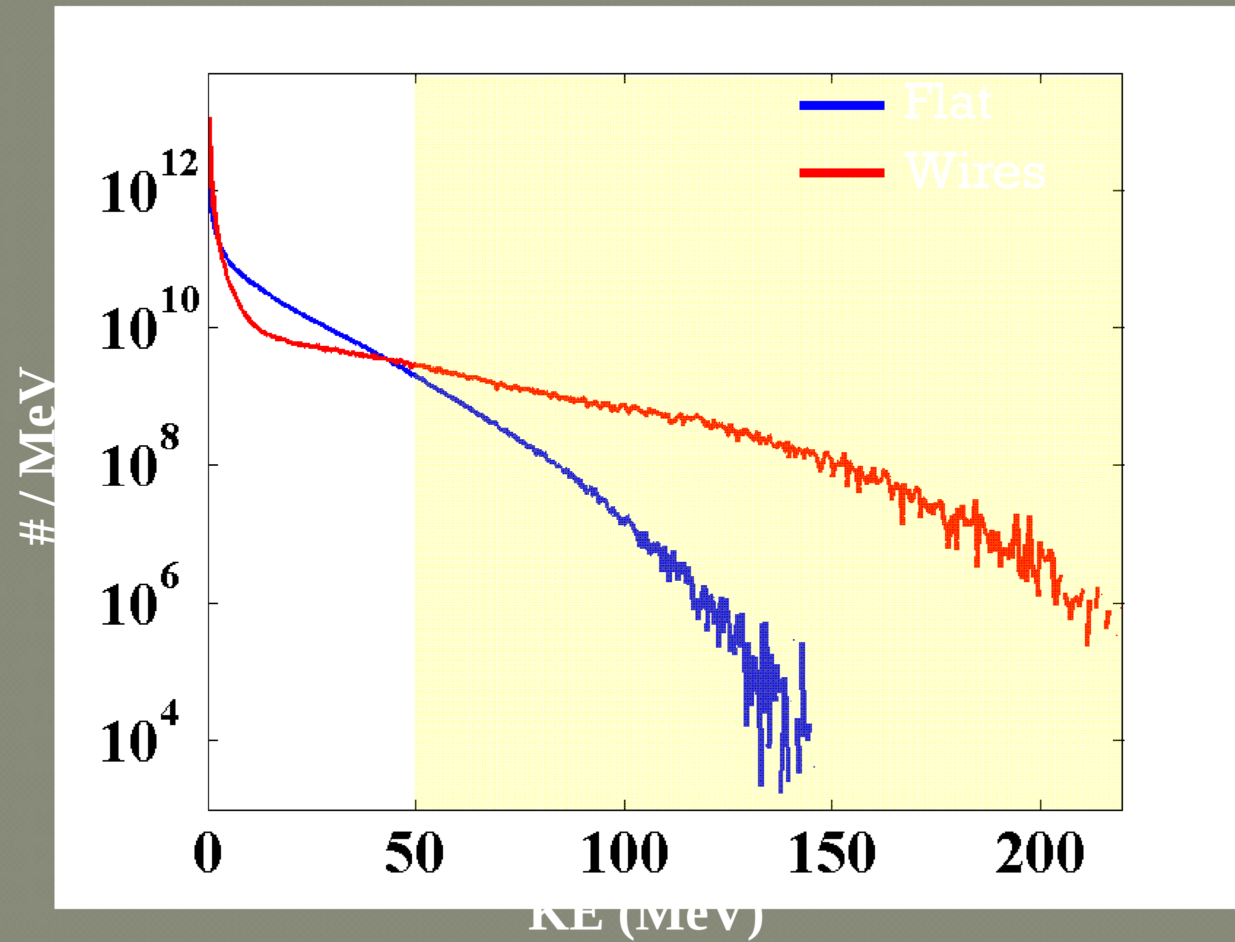
$\Delta z = 0.05\ \mu m$

$\Delta t = 0.03$ fs

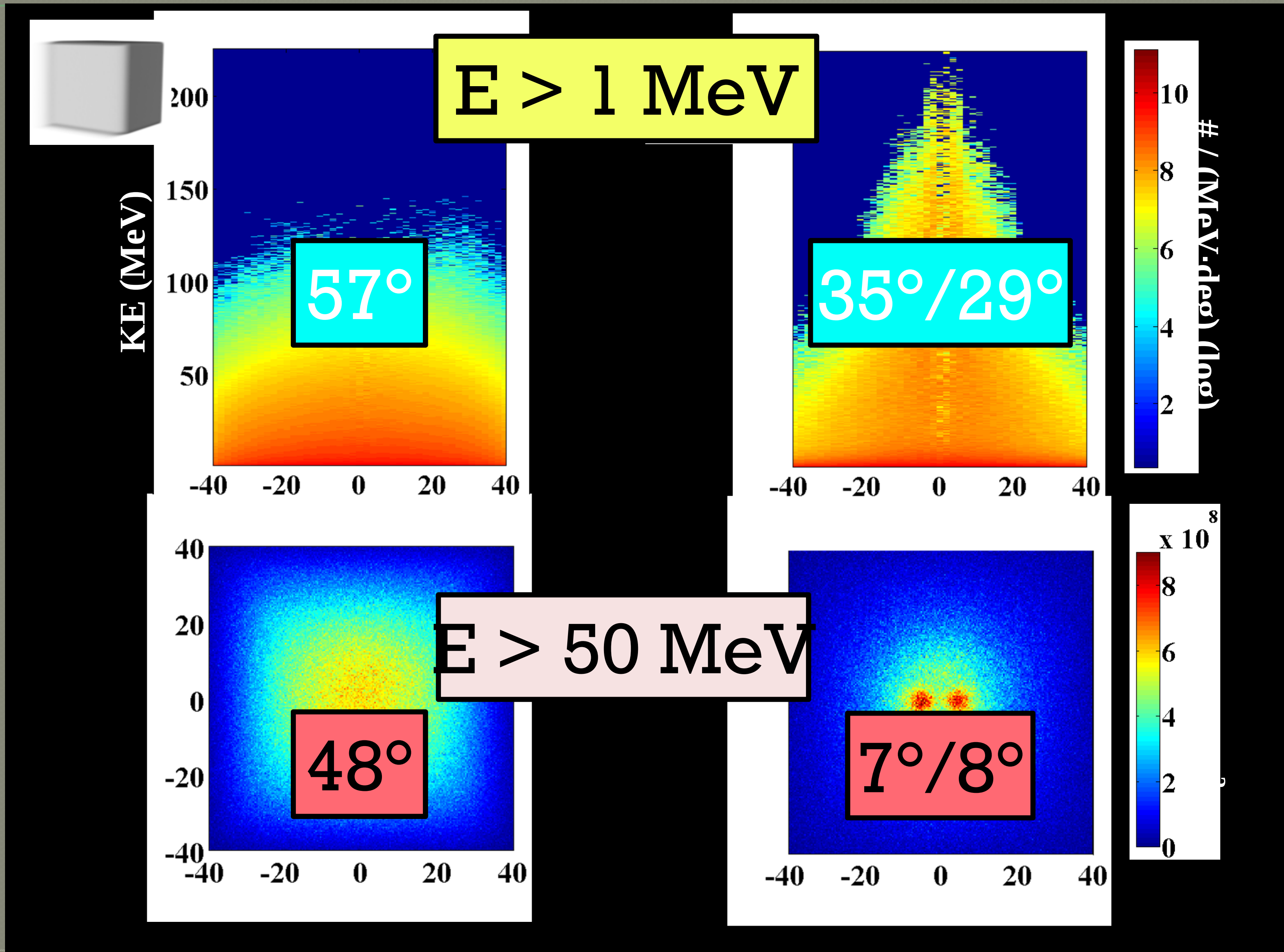
Structured targets show dramatic enhancement in hot tail



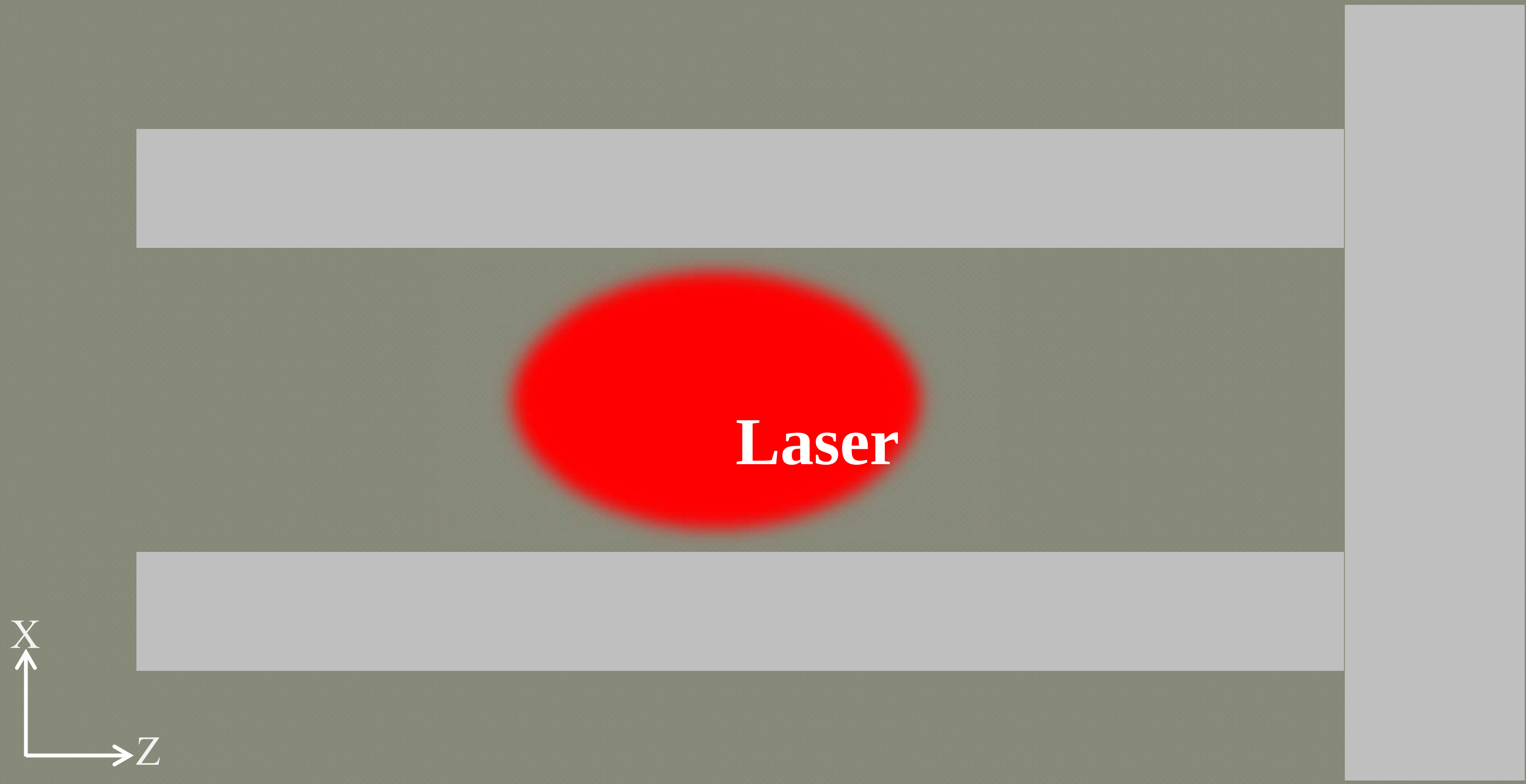




Structured targets also show dramatic narrowing

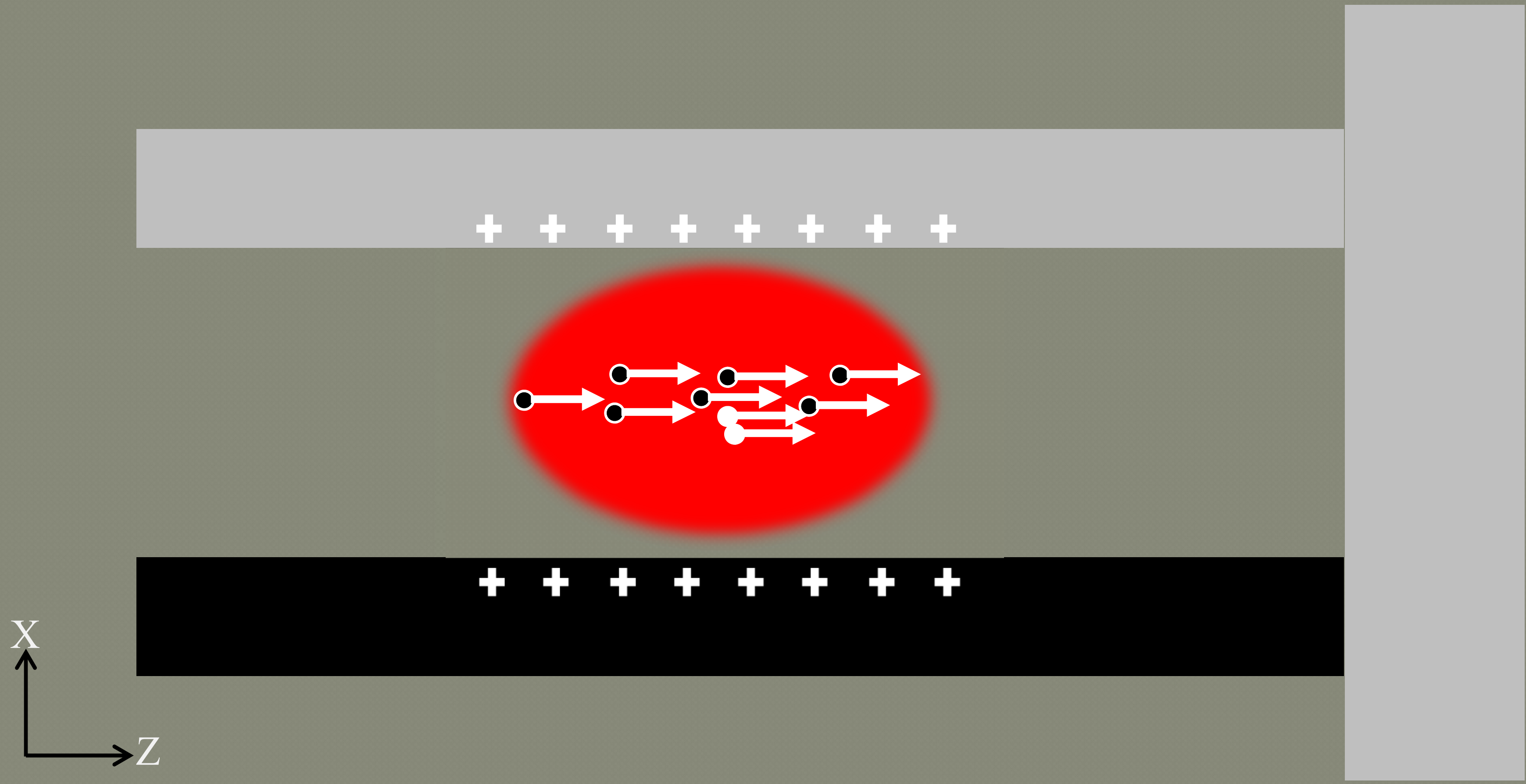


Narrowing of the electron distribution is caused by quasi-static fields

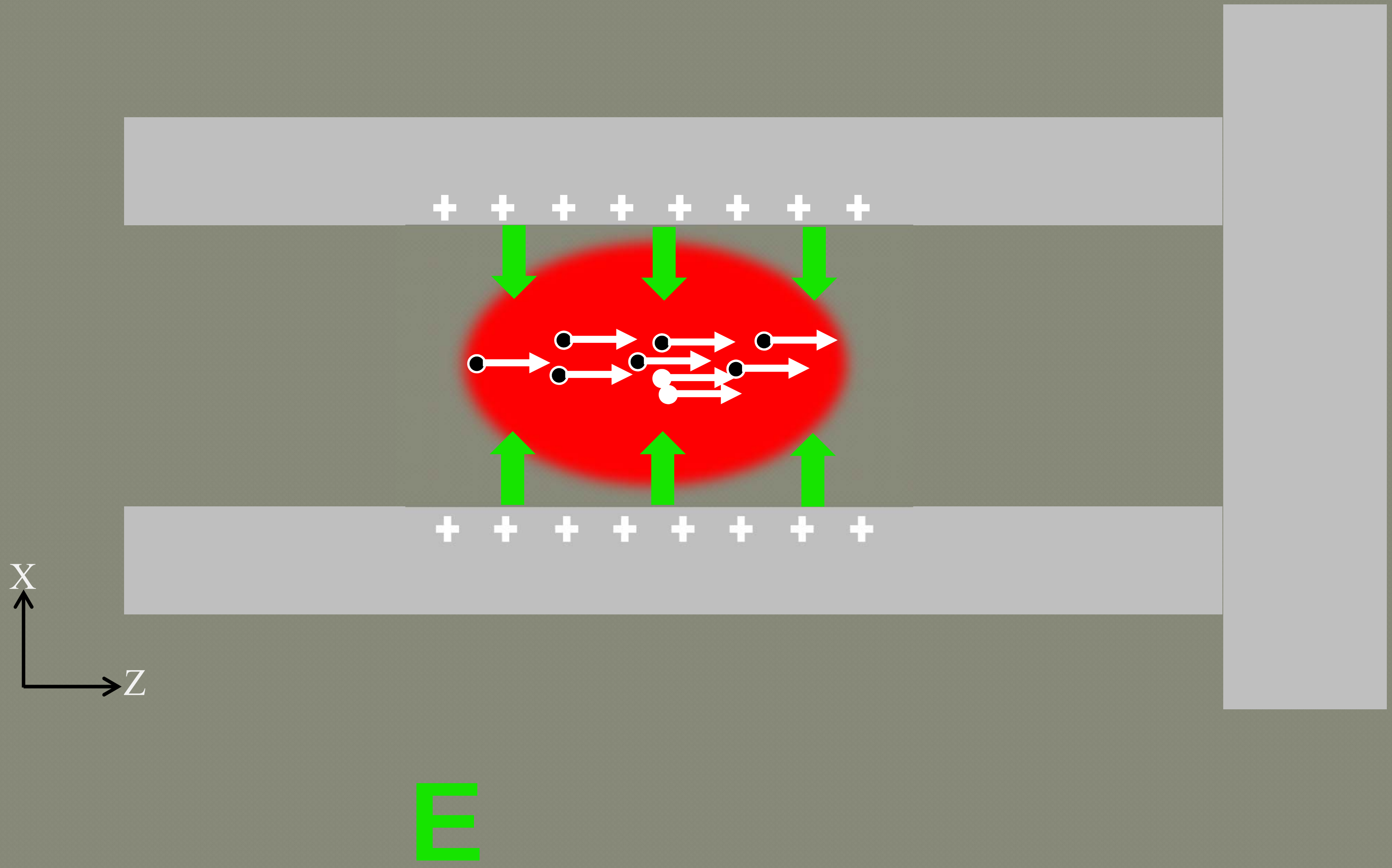


Y. Sentoku et al. Phy. Rev. Lett. 11, 3083 (2004).
S. A. Gaillard et al., Phys. Plasmas 18,9056710 (2011).
T. Kluge et al., New J. Phys. 14, 023038 (2012).

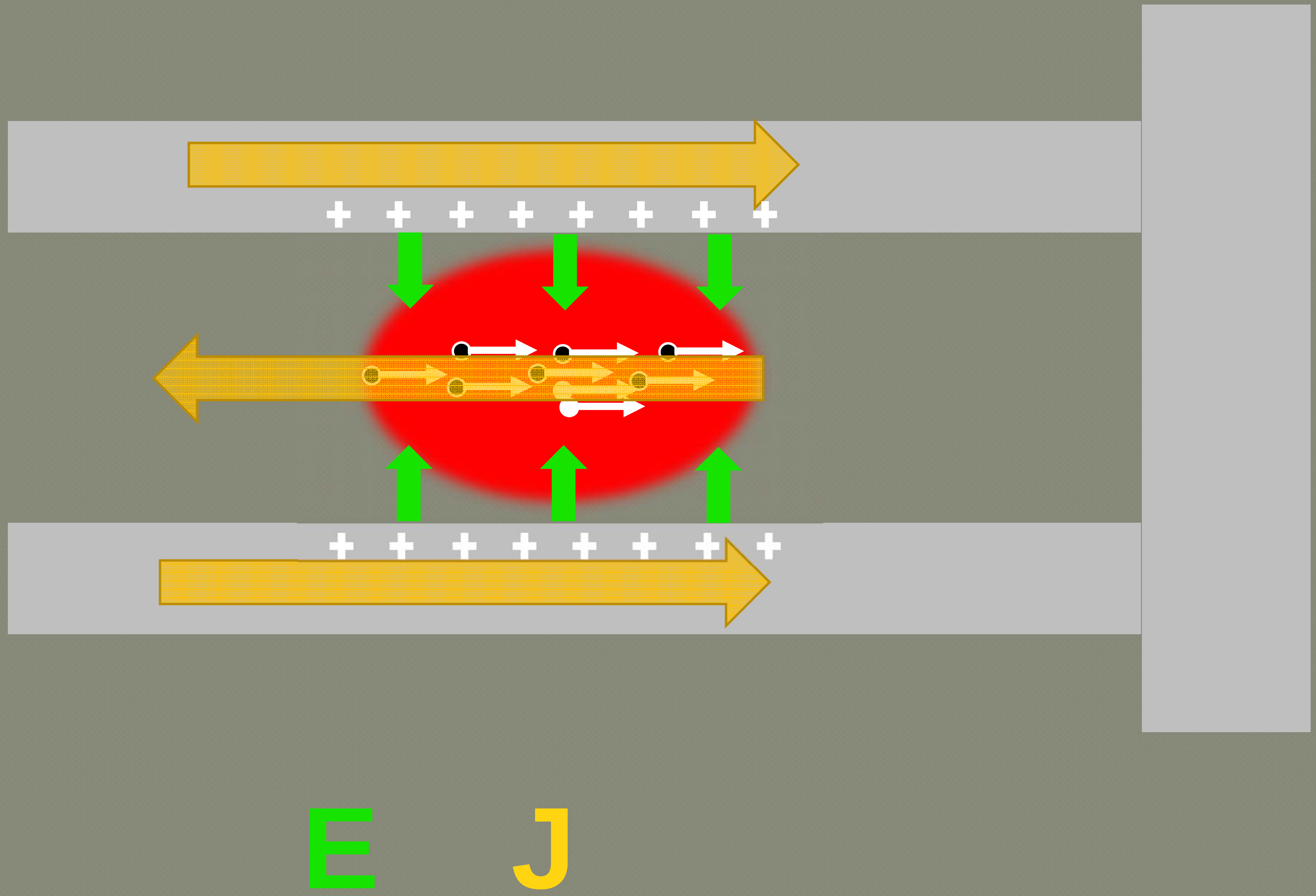
Electrons are pulled from the wires and accelerated directly by the laser



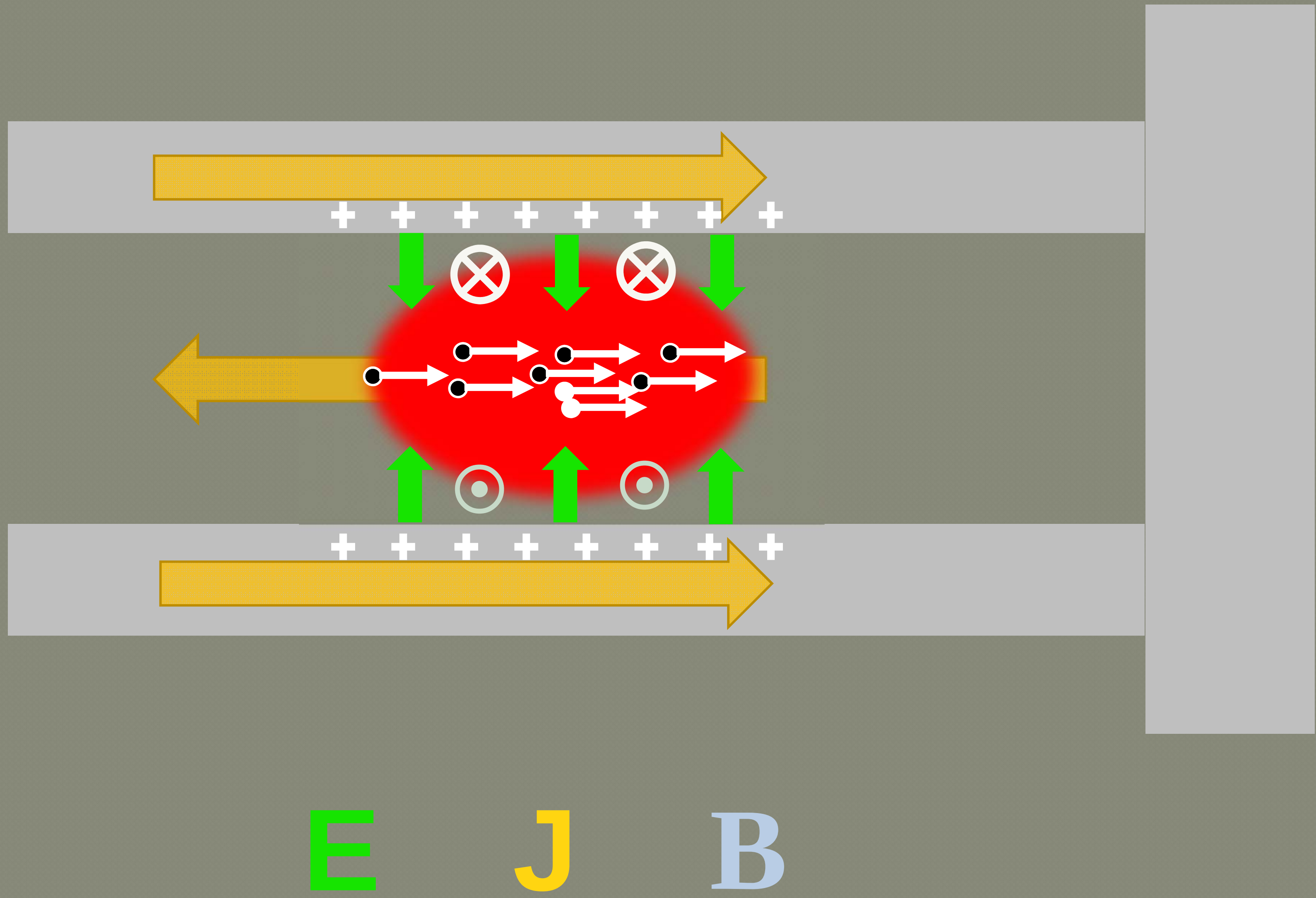
Surface E field is built up due to charge separation.



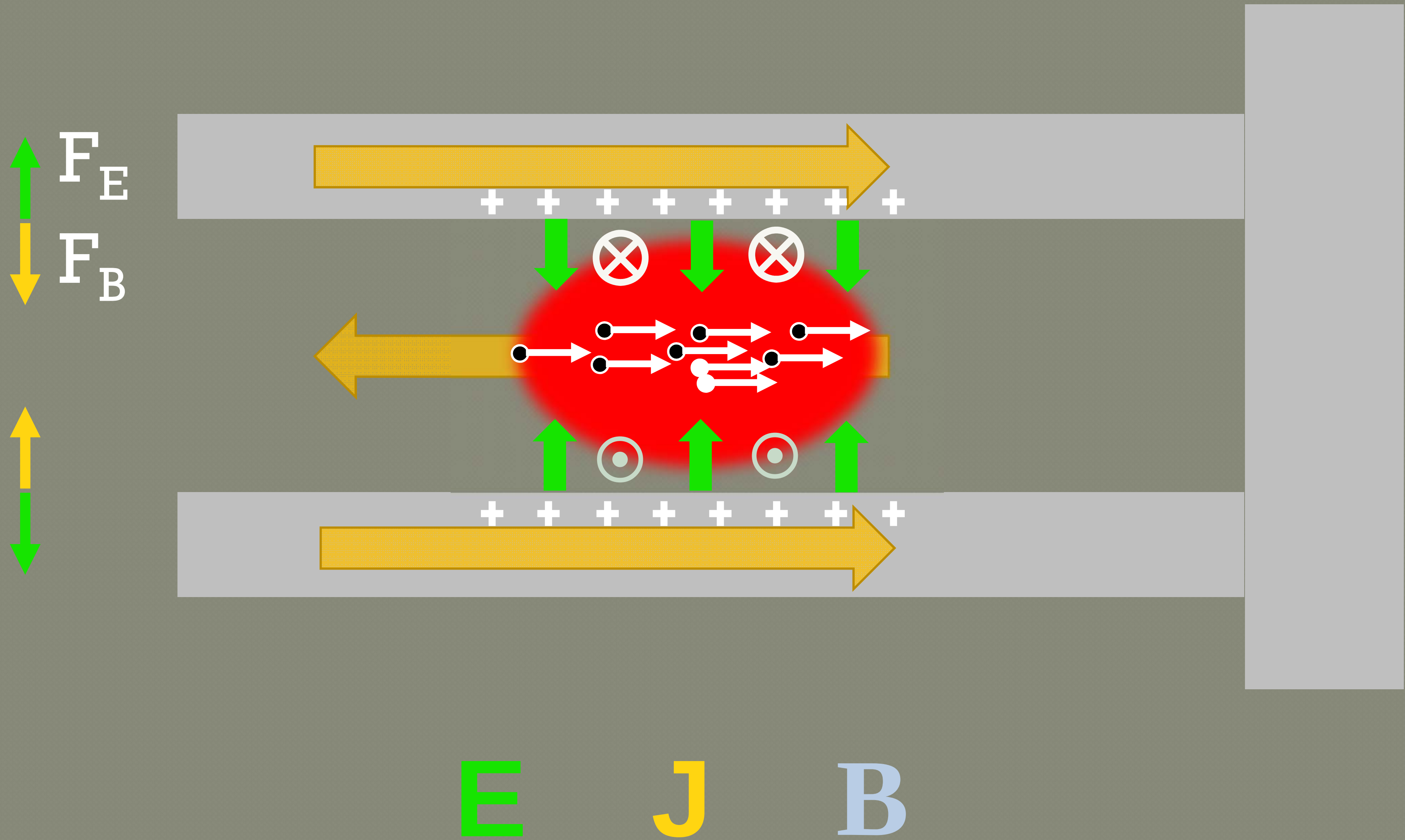
Hot and return currents produced by direct laser acceleration of electrons



Currents produce quasi-static magnetic field

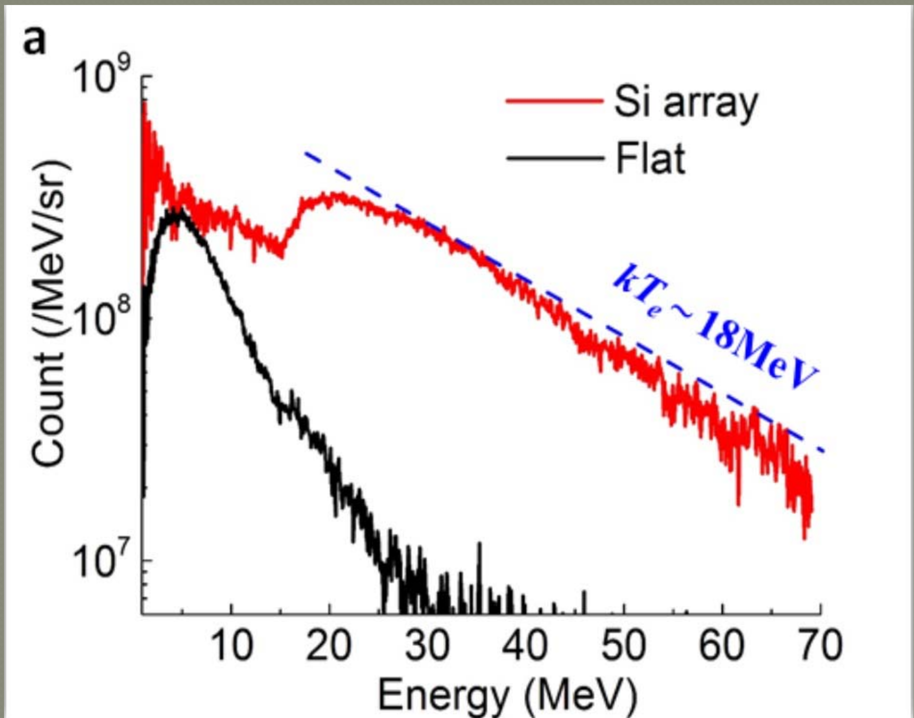


Opposing forces create a guiding effect along the wire surface

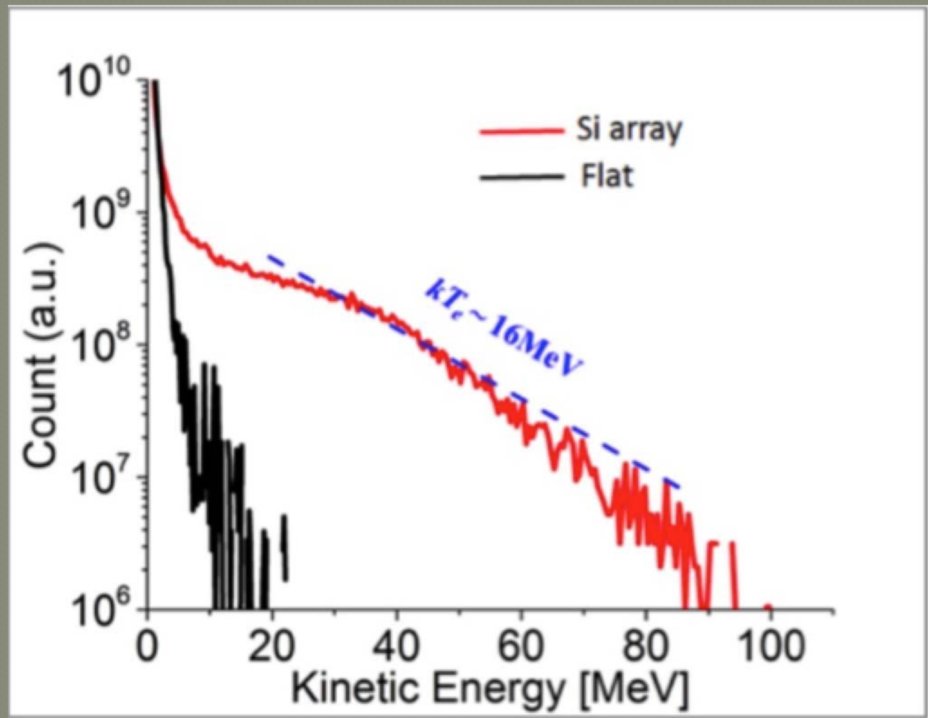


Comparison Between Experiment and Simulation

Experimental Result

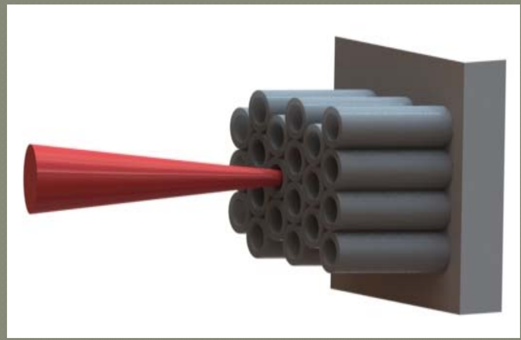


3-D Simulation

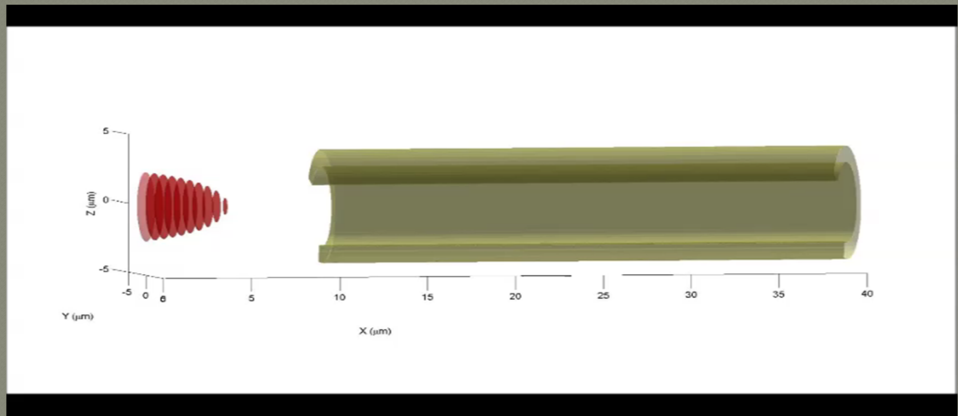


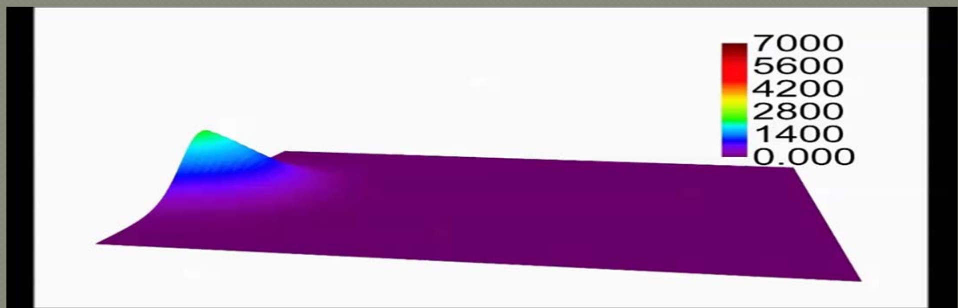
Effects of advanced targets on LPI

<u>Input laser:</u>
5.3×10^{21}W/cm^2
40fs

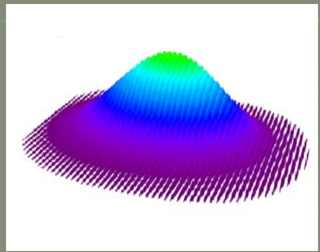


Carbon
n_e=300n_c
Diameter
4.8μm
Thickness
0.8μm

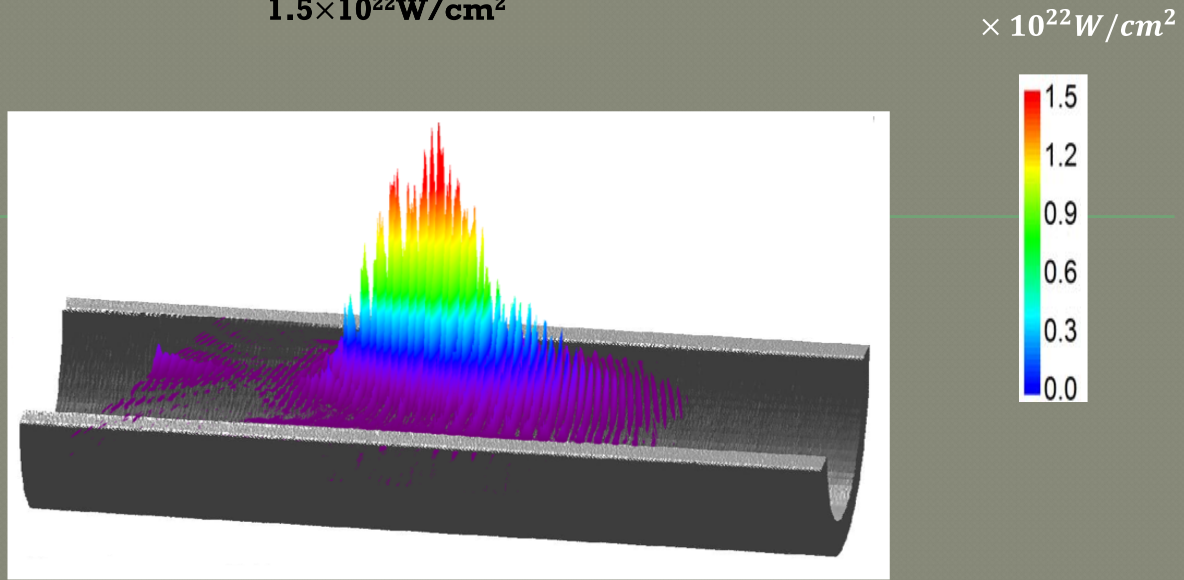


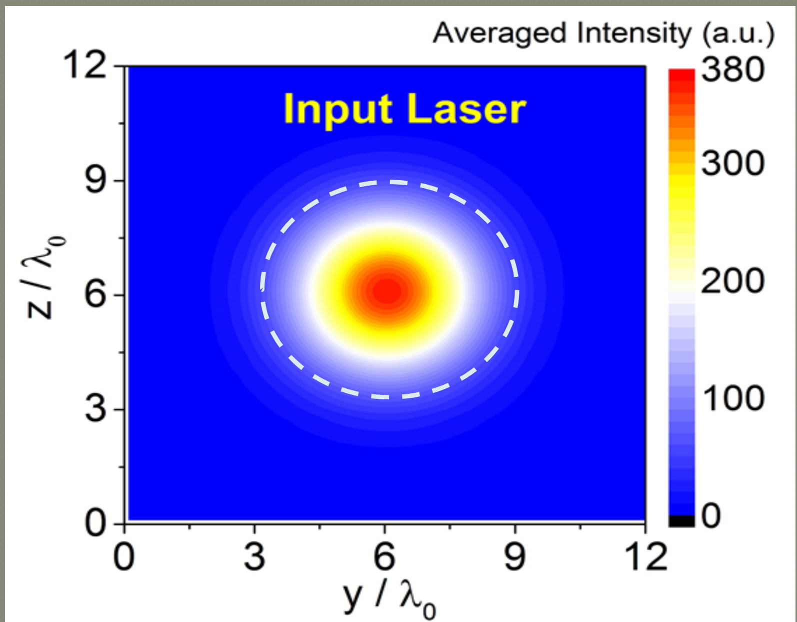


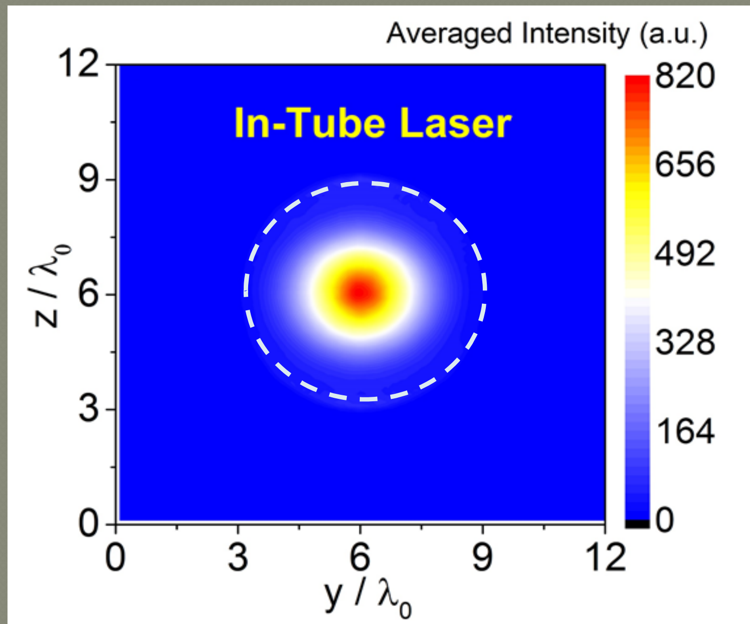
Input laser:
5.3×10^{21} W/cm^2



In-tube laser:
1.5×10^{22} W/cm^2

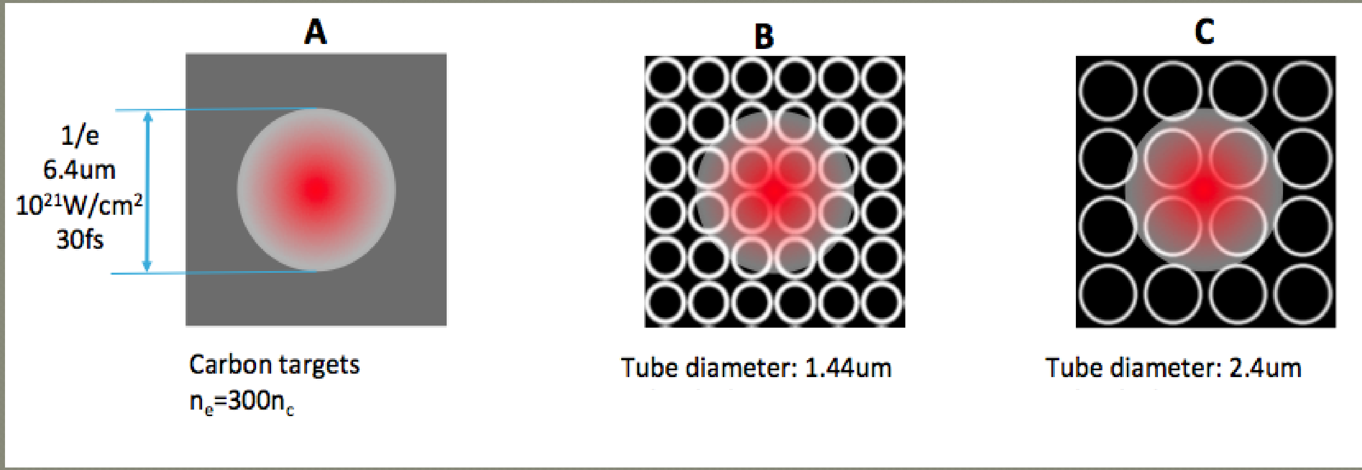


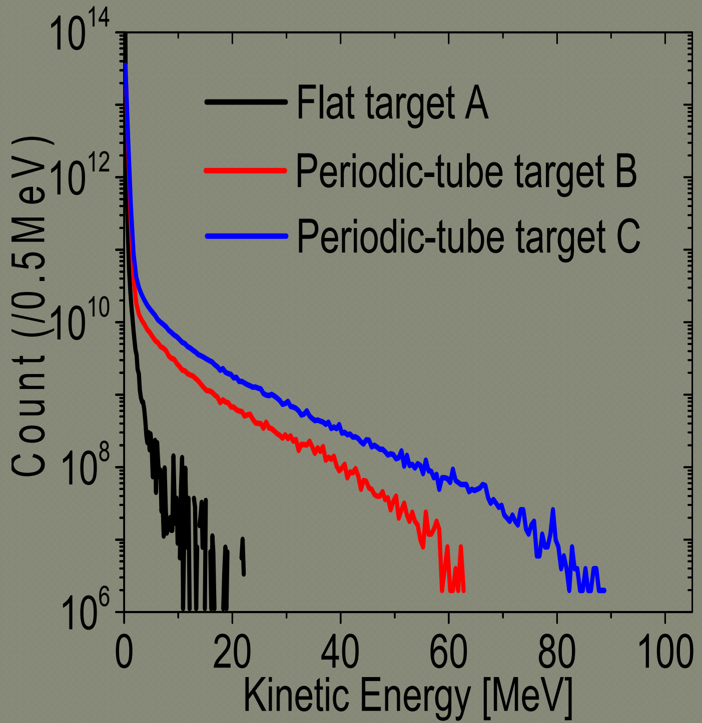




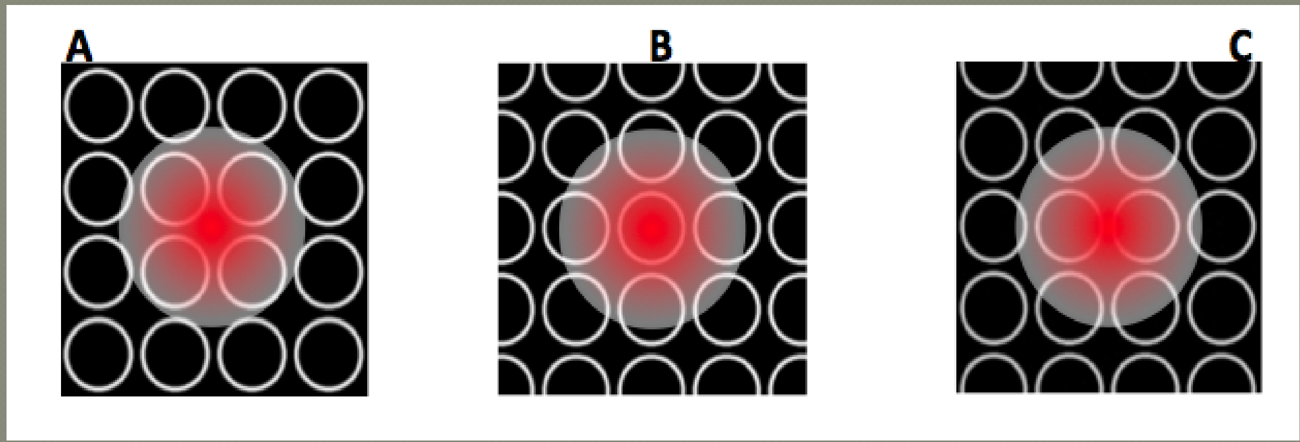
Intensification of a relativistic laser in a MTP target.

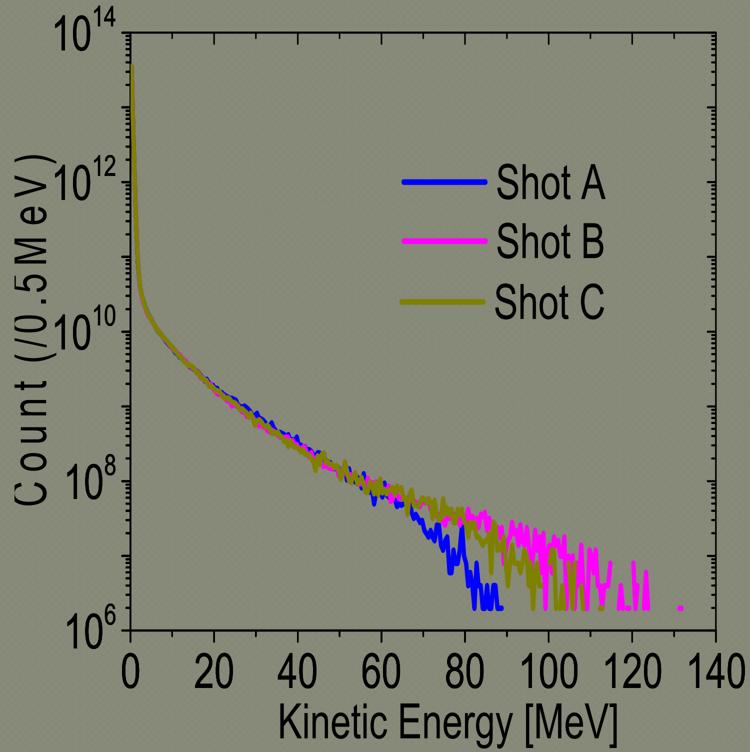
Electron beam as a function of tube diameter



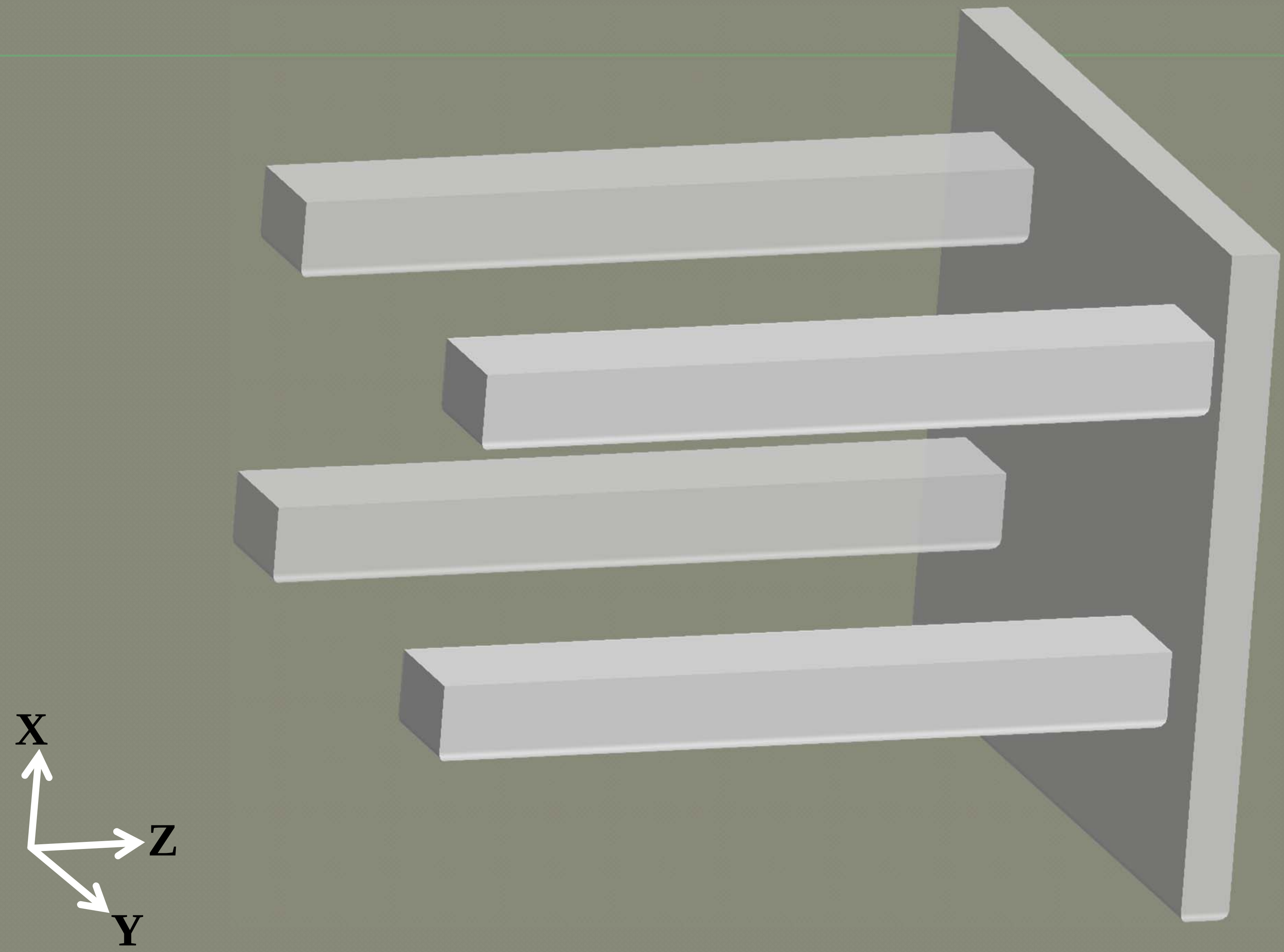


Effect of laser pointing on electron beam

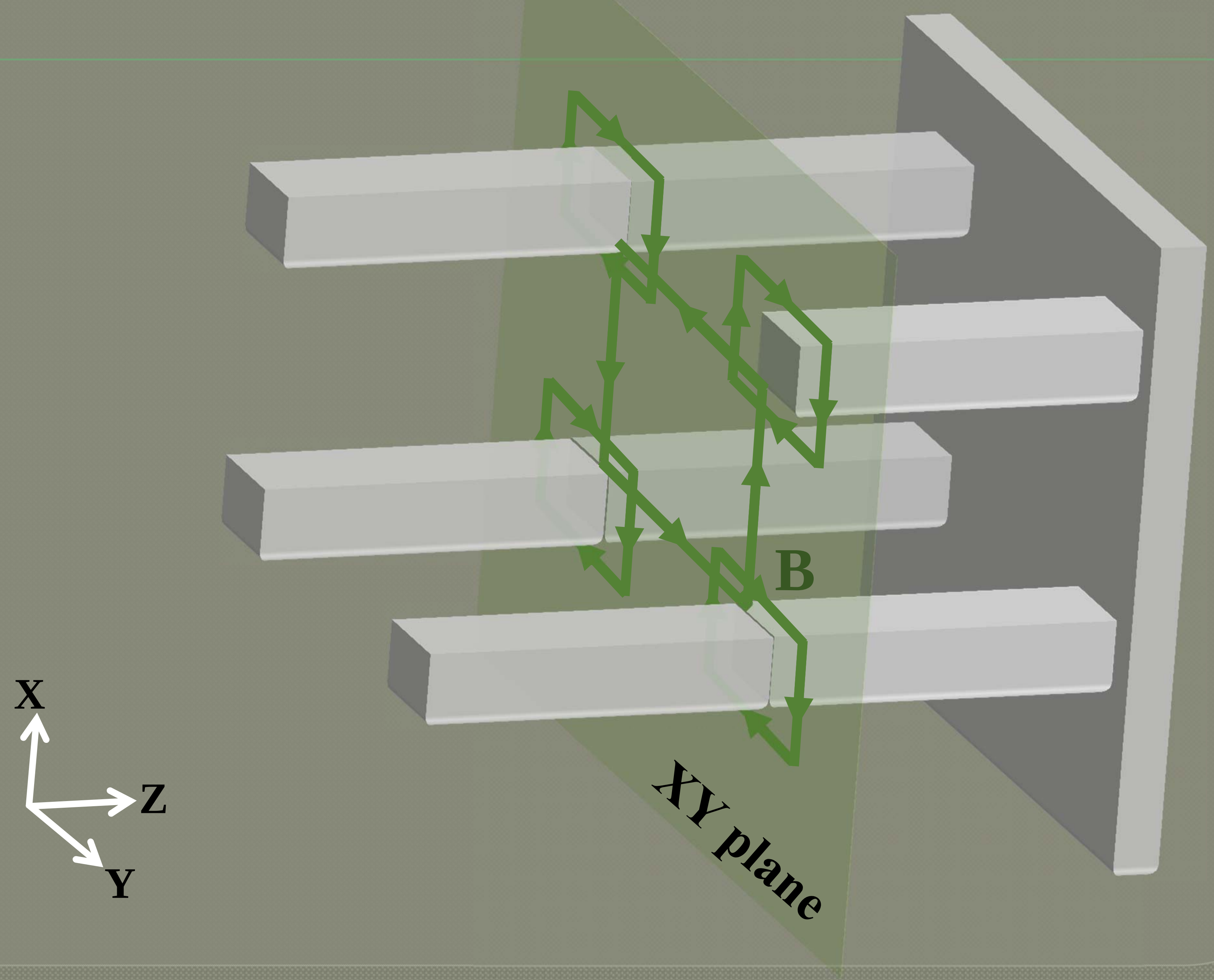




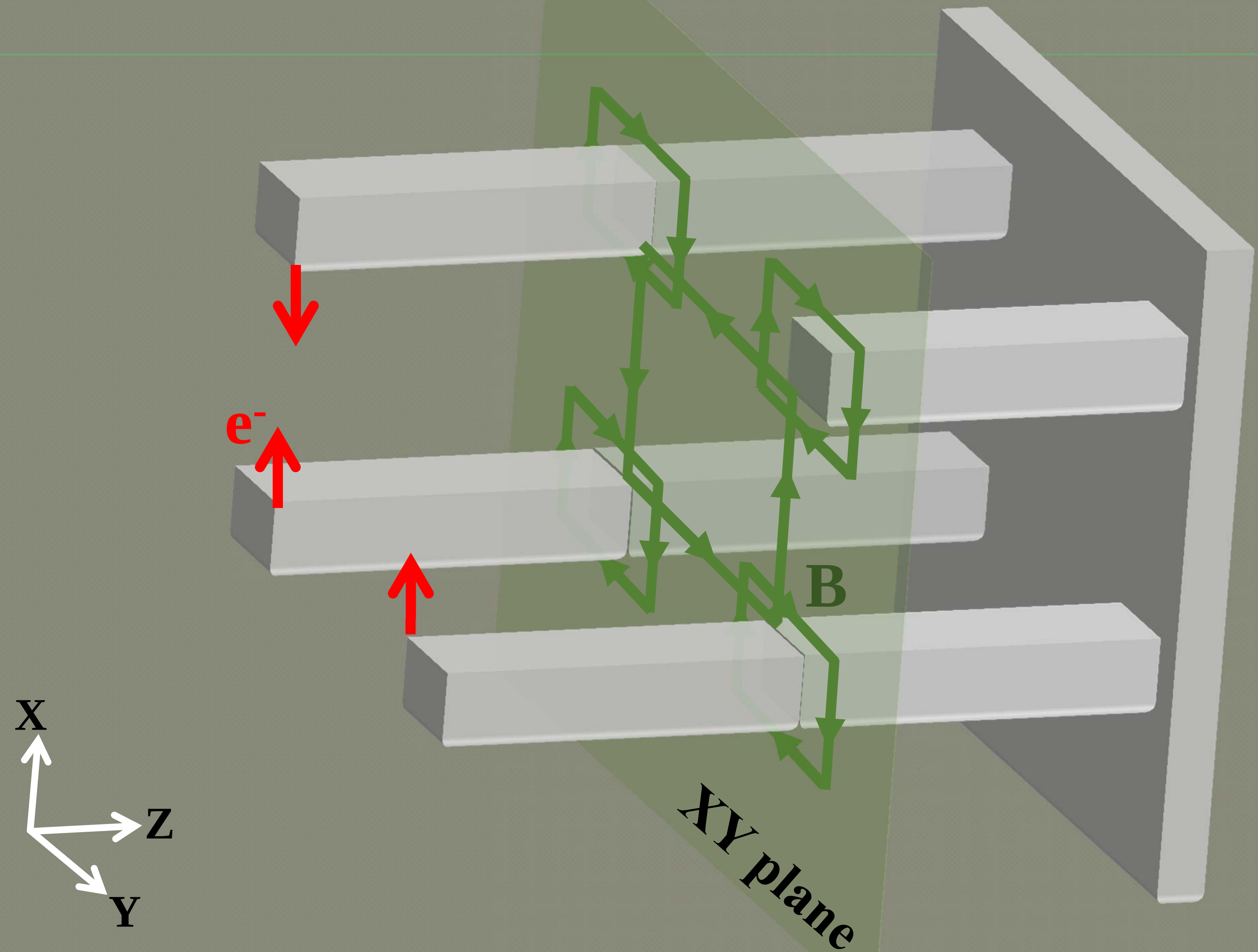
Reduced symmetry in 3D system produces different results



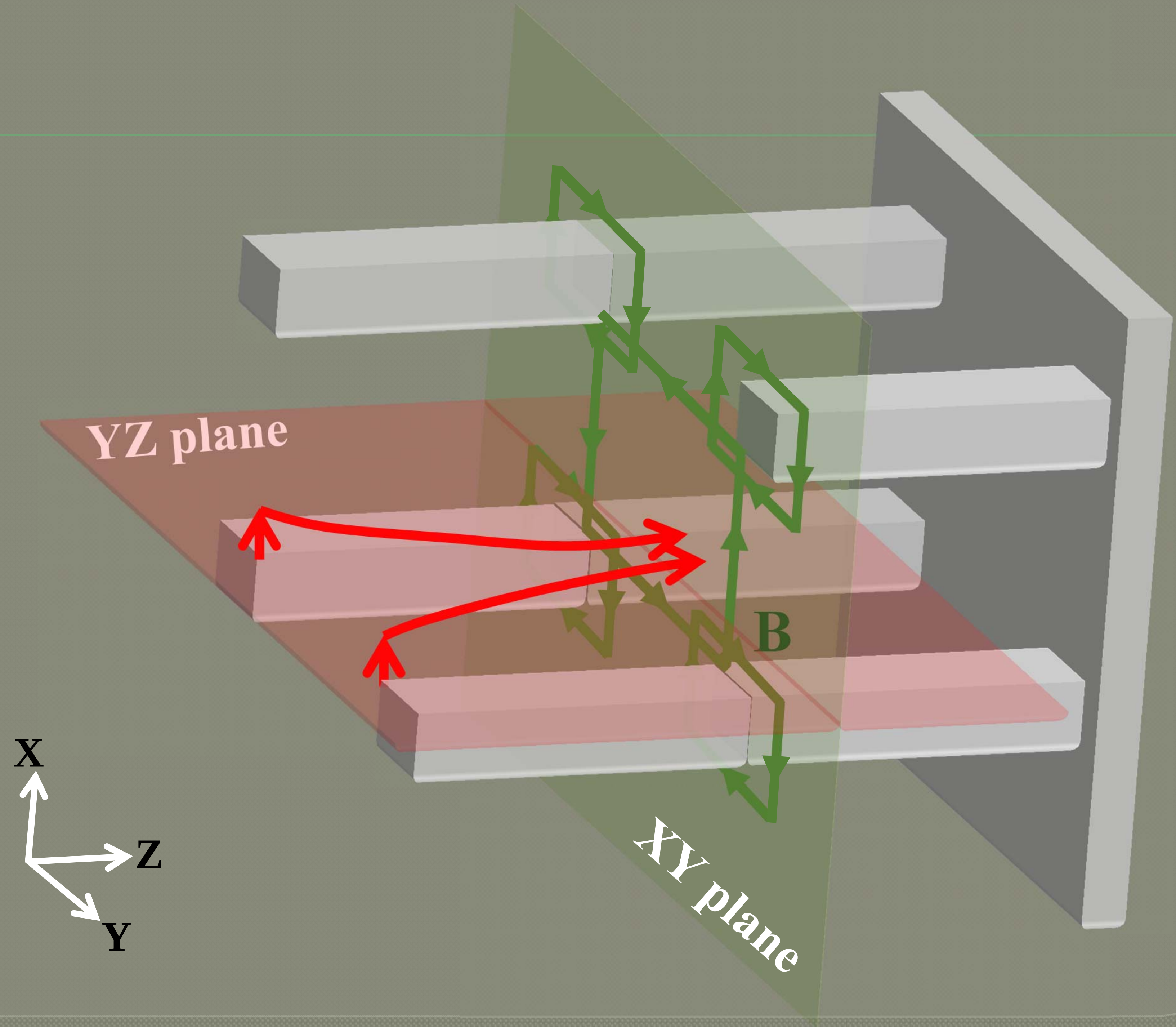
Magnetic field has quasi cylindrical symmetry



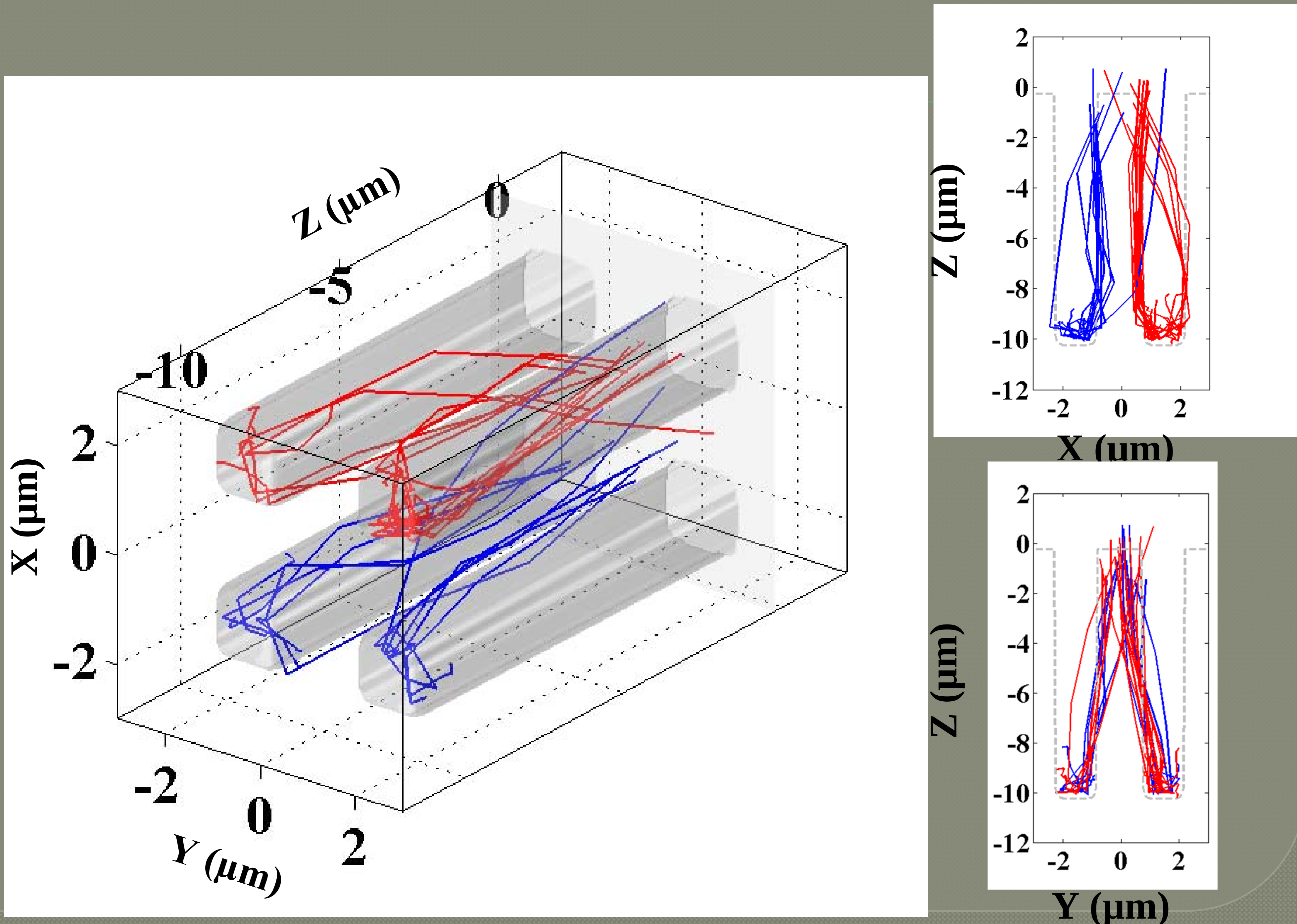
The electric field does not have the same symmetry



Electrons guided in X, pinched in Y



Effect shown clearly in particle tracks



We performed the experiment using the Scarlet laser facility at Ohio State

4 – 5 J

40 fs

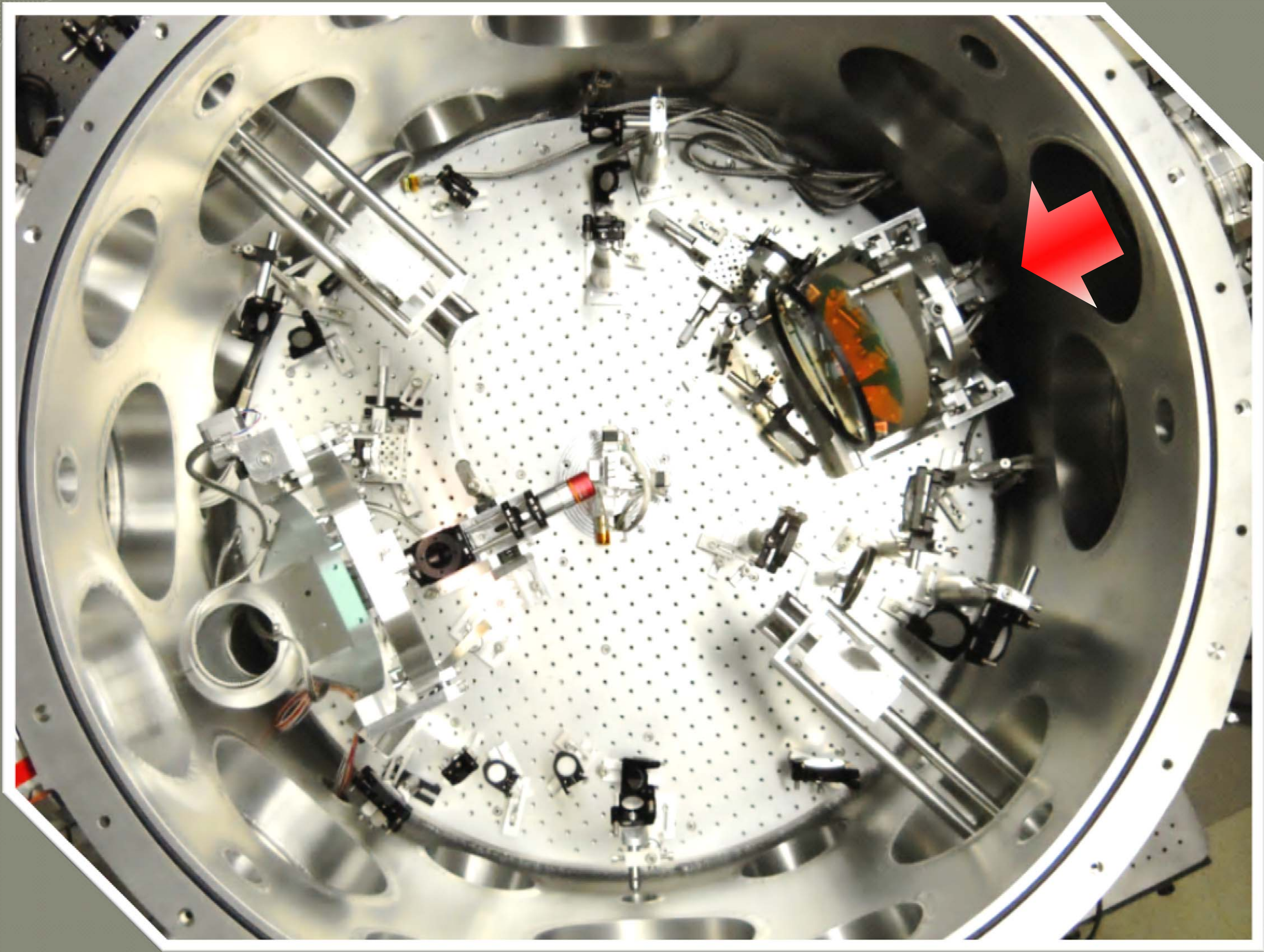
800 nm

We performed the experiment using the Scarlet laser facility at Ohio State

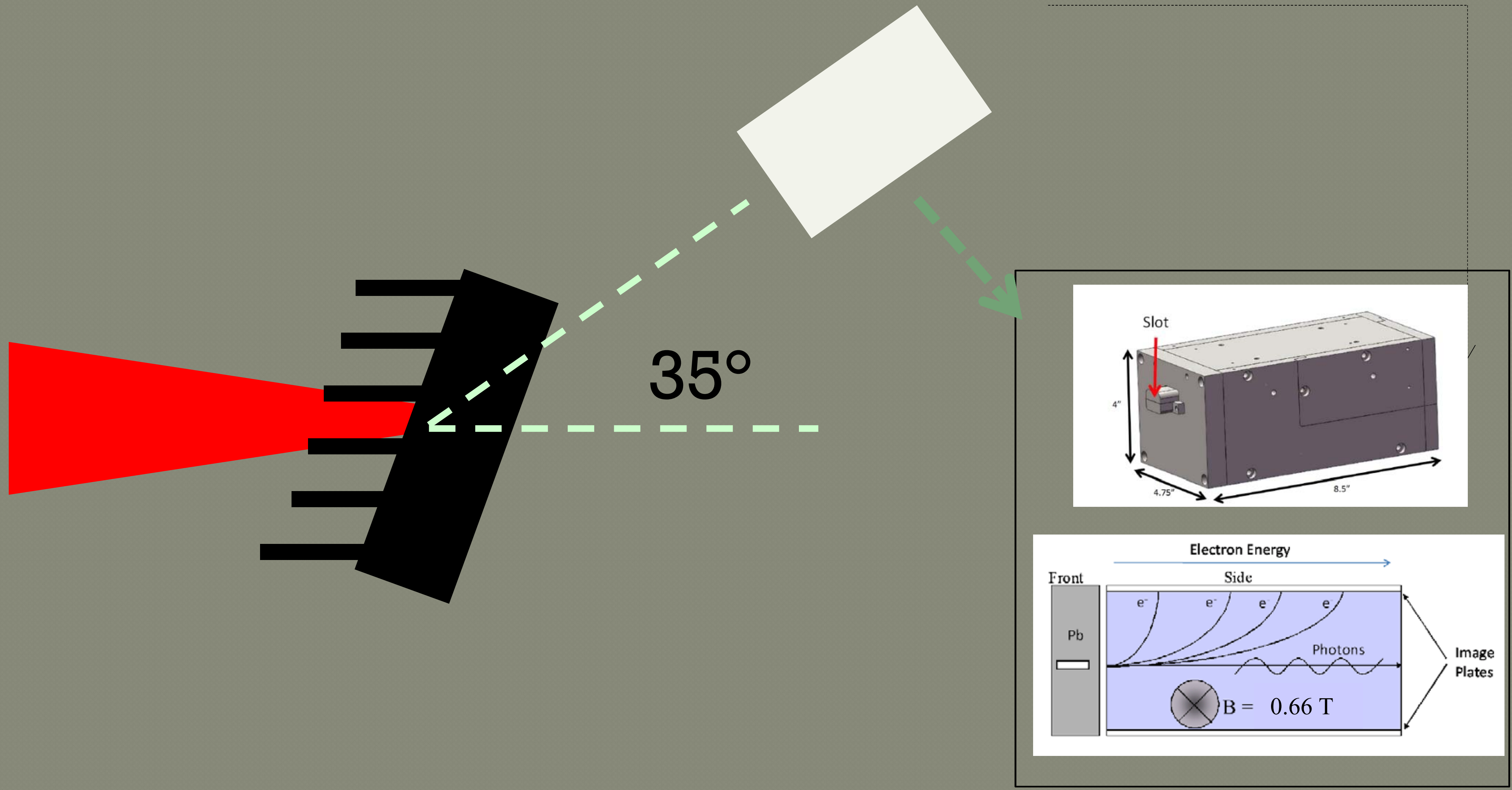
F/2.2 → 3 μm

$I/I_0 > 10^9$

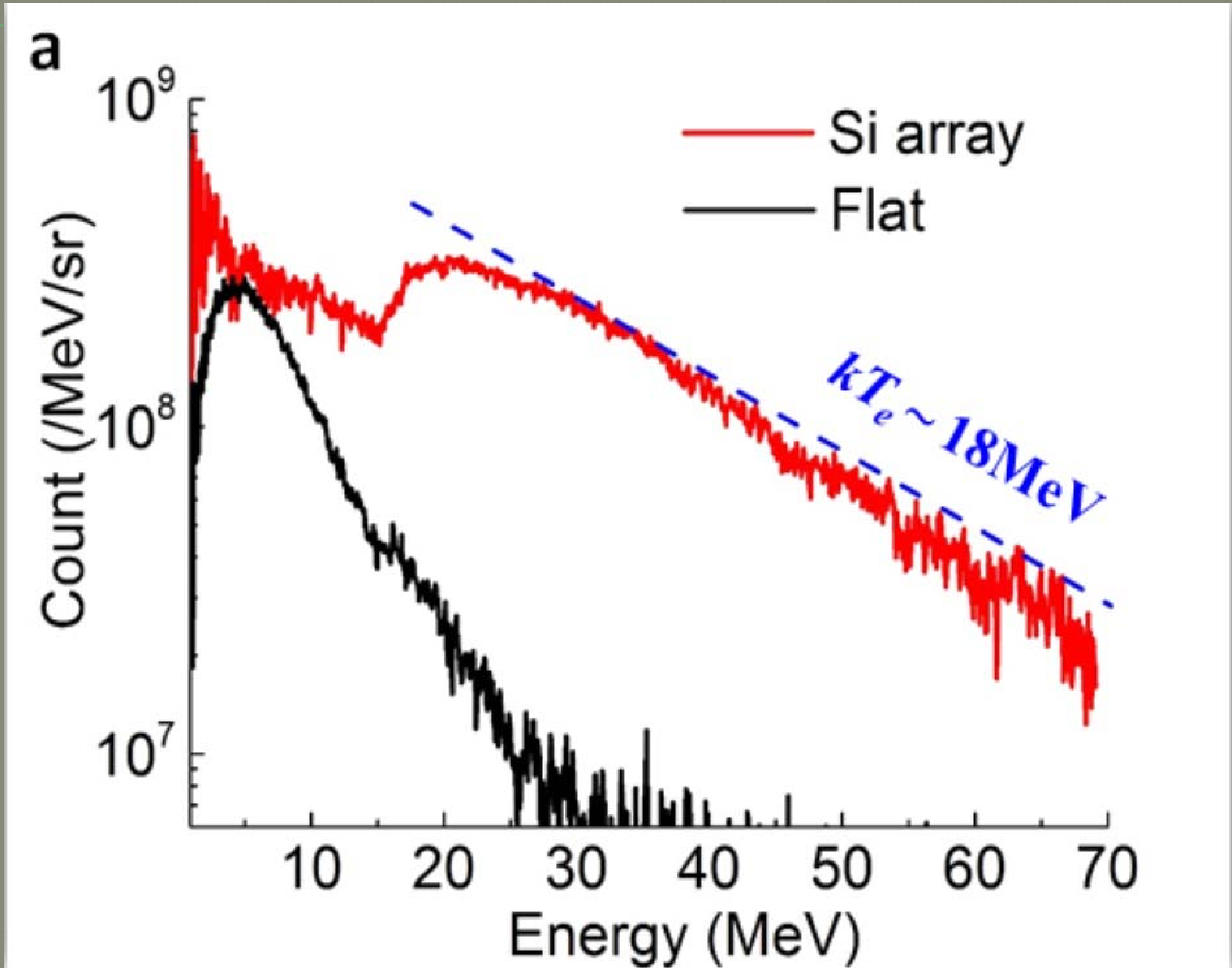
1×10^{21} W/cm^2



collected with magnetic spectrometer

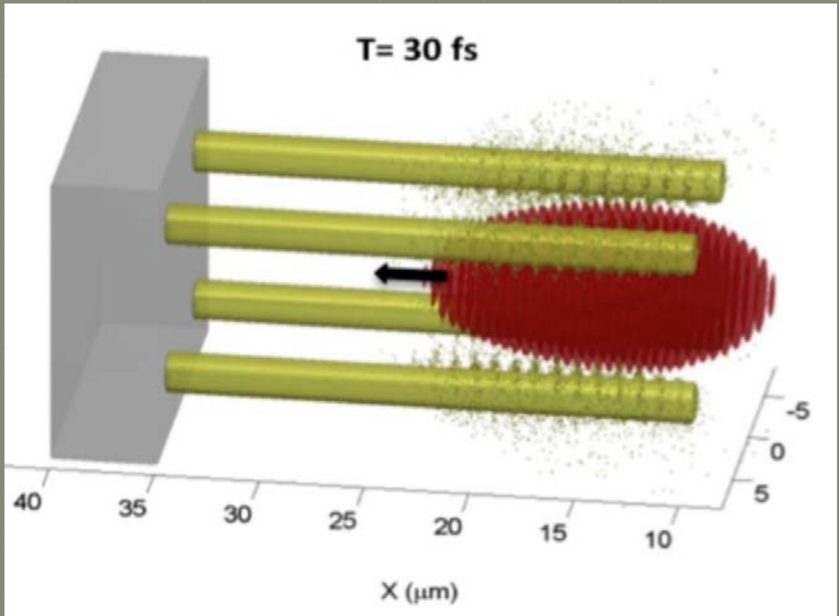


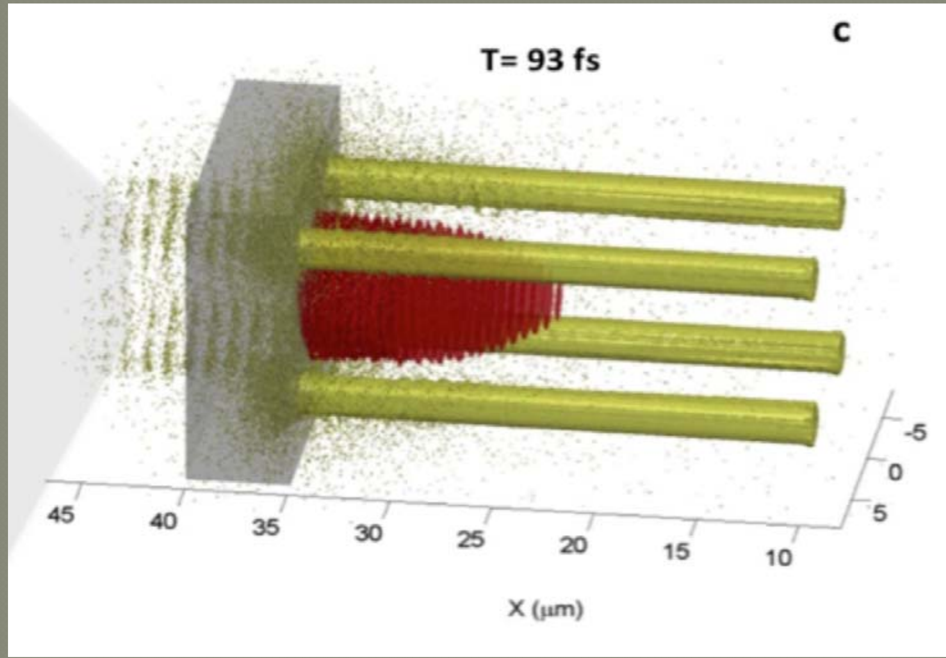
enhancement consistent with modeling



Ponderomotive scaling = 7 MeV

Hot electrons generated from two distinct spatial regions





spectrum predicted for structured targets