Enhanced laser-ion acceleration in thin foils of reduced surface

J. Psikal[1,2] (presenting author)

J. Fuchs[3], S. Buffechoux[3], V. Tikhonchuk[2] and others

[1] Faculty of Nuclear Sciences and Physical Engineering, Czech Technical University in Prague

[2] Centre Lasers Intenses et Applications, CEA – CNRS – Université Bordeaux 1

[3] Laboratoire pour l'Utilization des Lasers Intenses , CEA – CNRS – UPMC

Max-Planck-Institute Garching, 1st March 2010

other authors

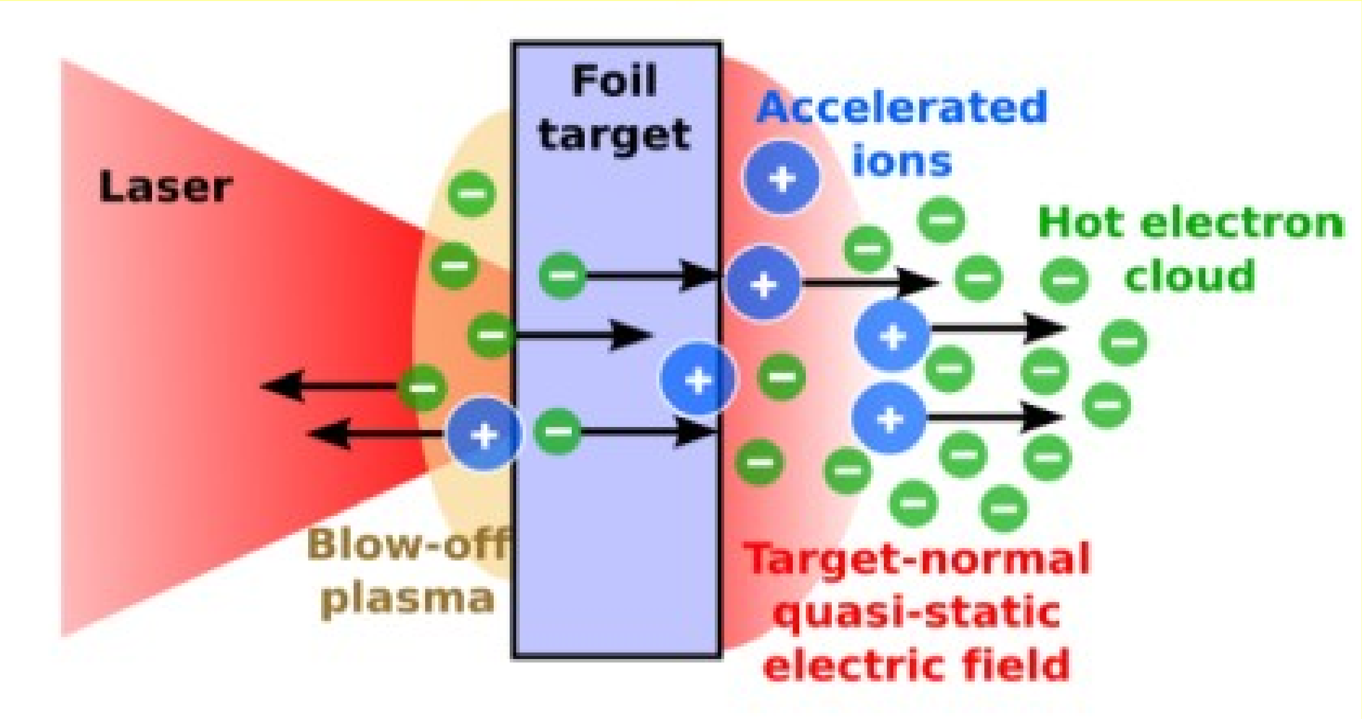
M. Nakatsutsumi, P. Antici, P. Audebert	LULI, Ecole Polytechnique, Palaiseau, France
S. Formaux, H. Pépin	INRS-EMT, Varennes, Québec, Canada
E. D'Humières	CELIA Bordeaux, France
L. Romagnani, G. Sarri, M. Borghesi	School of Mathematics and Physics, The Queen's University, Belfast, United Kingdom
A. Andreev	Vavilov State Optical Institute, St. Petersburg, Russia
K. Zeil, T. Burris, S. Gaillard, S. Kraft, U. Schramm, T. Cowan	Forschsungszentrum Dresden Rossendorf, Germany
M. Amin, T. Toncian, O. Willi	Institut für Laser und Plasma Physik, Heinrich-Heine-Universität Düsseldorf, Germany
A. Compant-La-Fontaine, F. Gobet, F. Hannachi, C. Plaisir, M. Tarisien	Université de Bordeaux, Centre d'Etudes Nucléaires Bordeaux Gradignan, France
M. Tampo	Kansai Photon Science Institute, Japan Atomic Energy Agency, Kyoto, Japan

Why laser-driven ion accelerators?

- very short laser pulses (10's-100's fs) of a high intensity ($I\lambda^2 > 10^{18}$ W/cm$^2\mu$m^{-2}) => electron motion in laser fields becomes relativistic => ions can be accelerated to MeV energies on a very short distance (several μm) by electrostatic fields ($\approx 10^{12}$ V/m) generated by electrons
- conventional particle accelerators – the strength of accelerating fields $\approx 10^8$ V/m
- applications: medicine (proton/hadrontherapy, PET, ...), radiography, neutron sources (imaging), transmutation of nuclear materials, fast ignition, ...
- problems: <u>high energy and large flux of ions</u>, monoenergetic beams, reproducibility, reliability

Ion acceleration mechanisms

- <u>TNSA – target normal sheath acceleration</u>
- radiation pressure acceleration (RPA), laser break-out afterburner (BOA), ...



  - accelerated ions – usually protons from hydrocarbon or water deposits on the foil surface

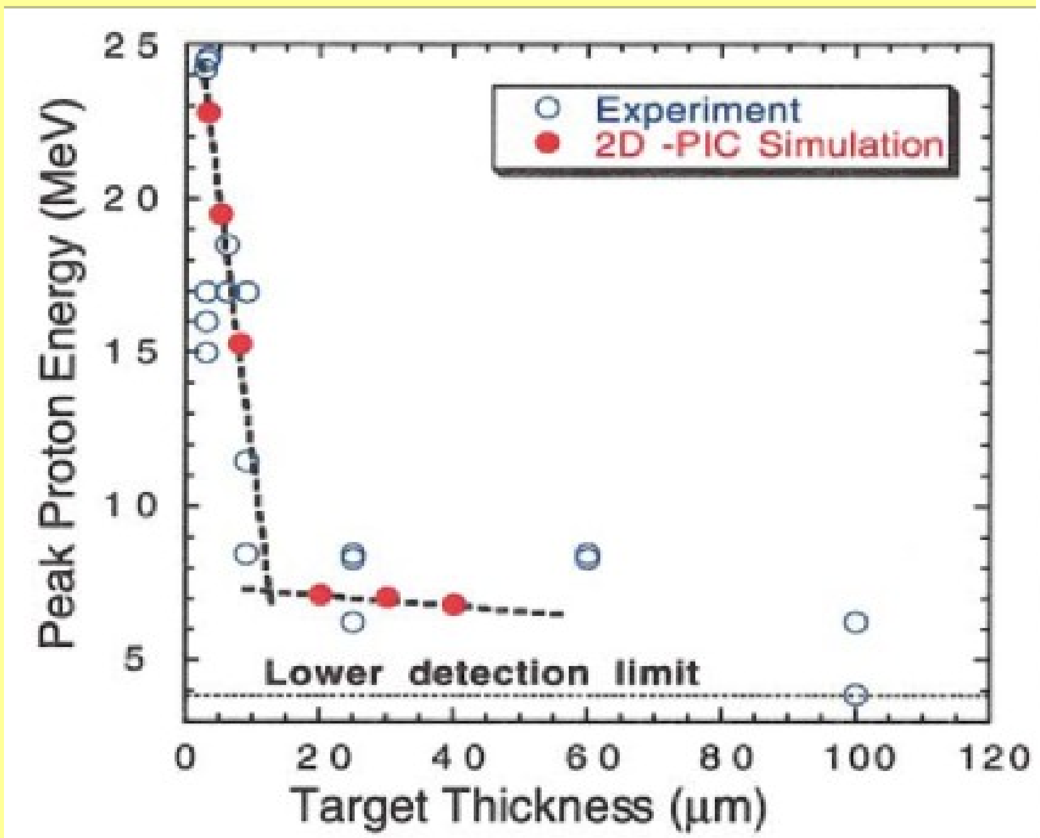
How to increase the efficiency of

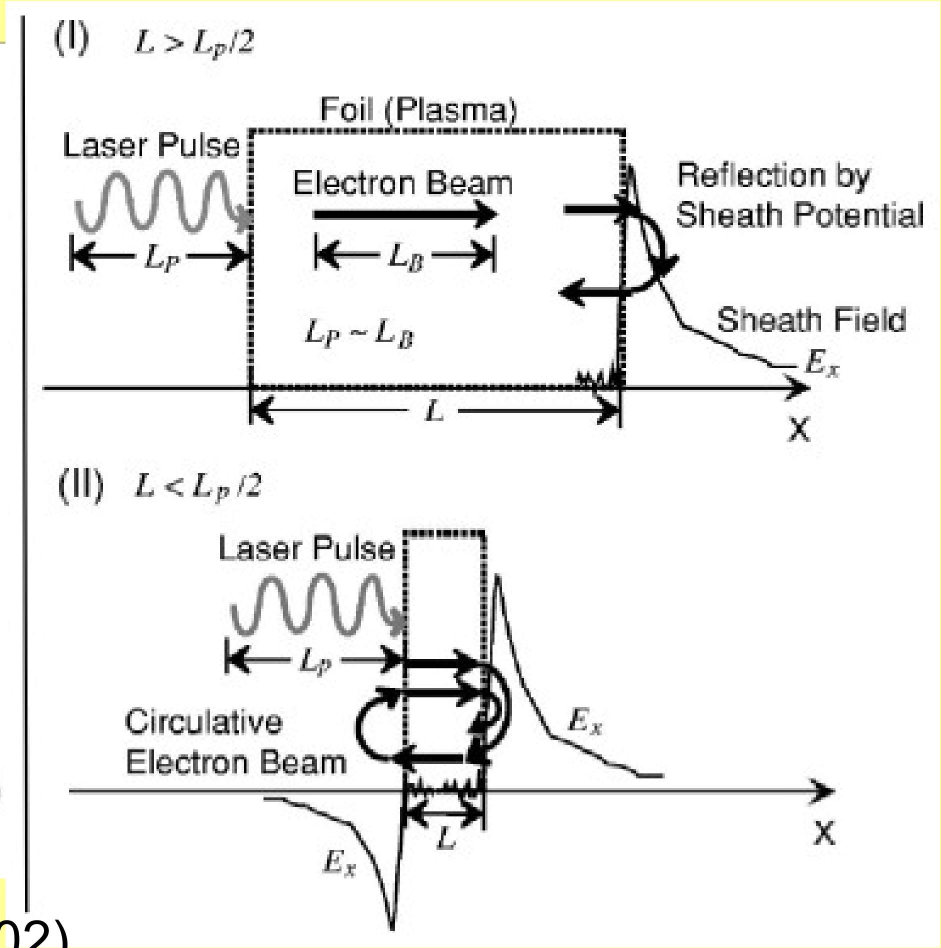
TNSA mechanism?

(enhancement of maximum proton energy,
laser-to-proton energy conversion efficiency,
reduction of proton beam divergence)

Recirculation of hot electrons in longitudinal direction

- thin foils – recirculation of electrons forth and back

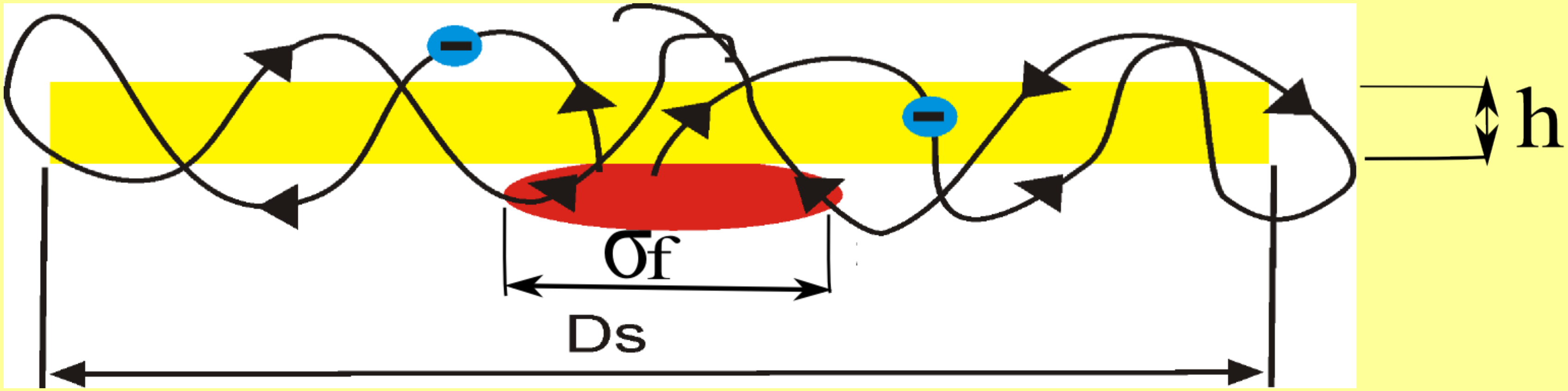




A. J. Mackinnon *et al.*, PRL **88**, 215006 (2002)

Y. Sentoku *et al.*, Phys. Plasmas **10**, 2009 (2003)

Transverse refluxing of hot electrons



key ratio – $D_s/(c\tau_L)$;

σ_f - focal spot size

D_s - transverse target size,

$(c\tau_L)$ - spatial laser pulse length

h – target thickness $h \ll c\tau_L$

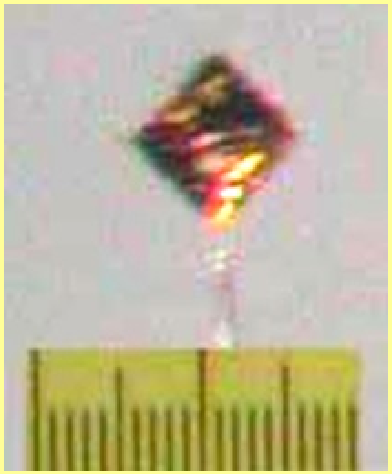
velocity of transverse sheath spread ≈ c

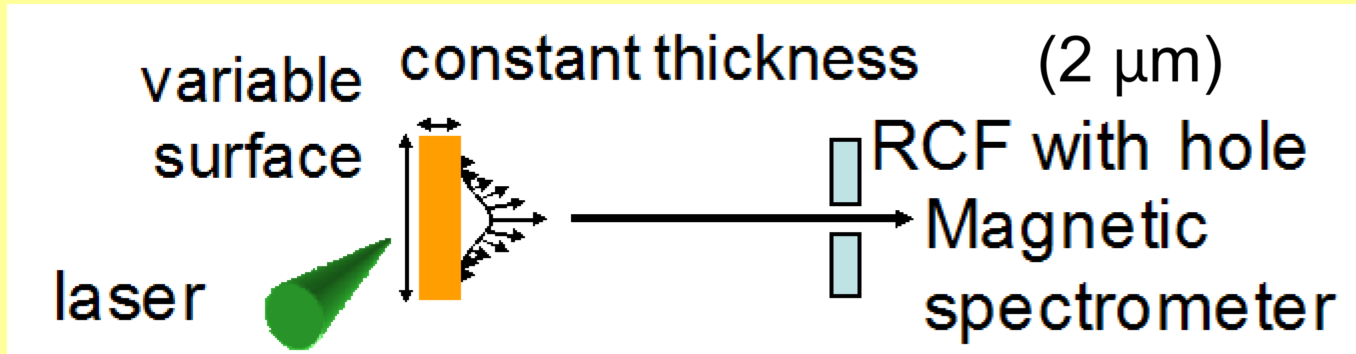
- $D_s \gg c\tau_L$: thin foils (already studied)
- $D_s \approx c\tau_L$, $D_s \gg \sigma_f$: **thin foils of reduced surface**
- $D_s \ll c\tau_L$, $D_s \approx \sigma_f$: mass-limited targets

P. McKenna *et al.*, PRL **98**, 145001 (2007)

J. Limpouch *et al.*, Laser Part. Beams **26**, 225 (2008)

Experiments with thin Au foils at LULI

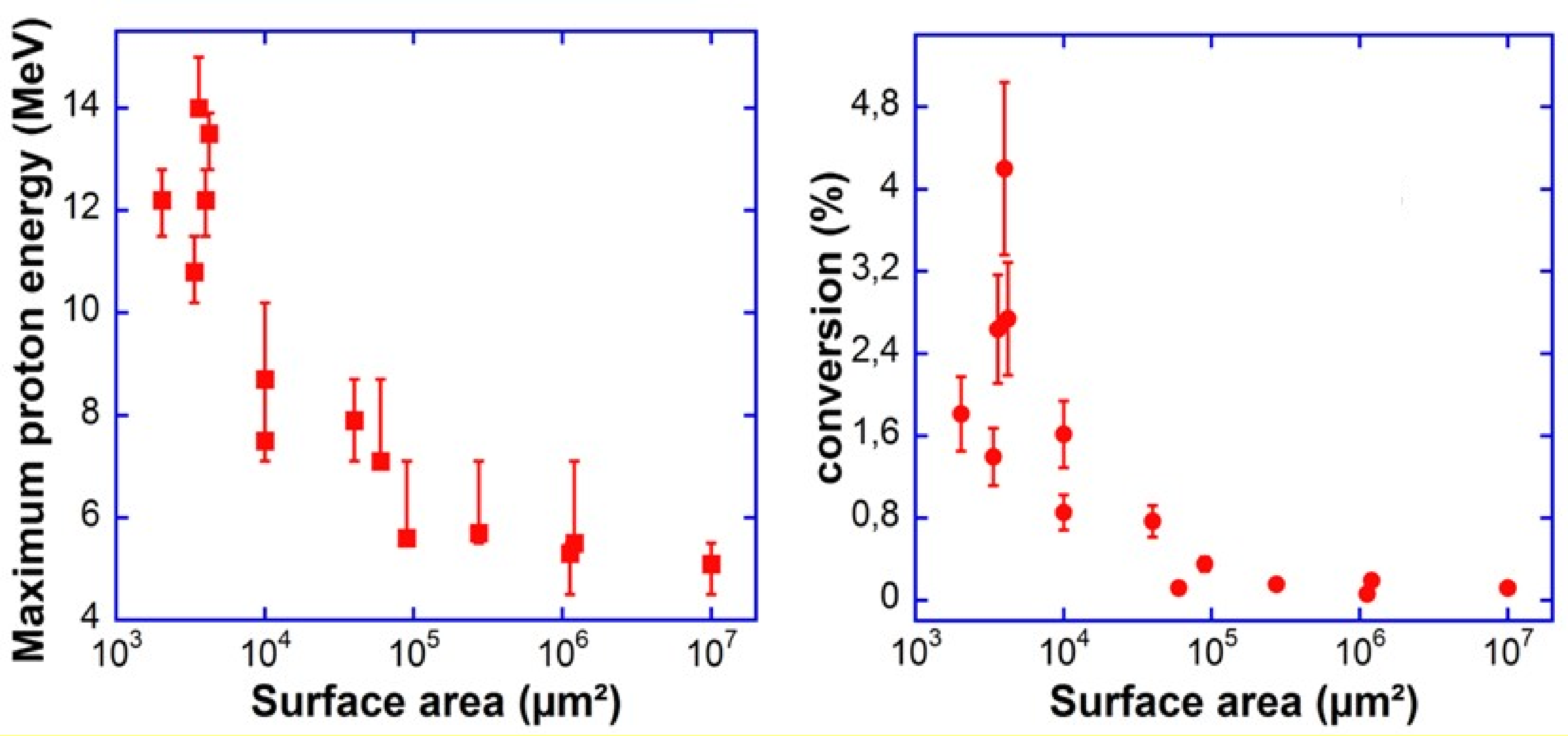




- laser pulse duration 400 fs, frequency-doubled and filtered at 529 nm in order to enhance its temporal contrast, s-polarized
- the laser was focused to ~6 µm (FWHM), at 45° incidence, and at the center of Au targets
- laser energy in focal spot $E_L \sim 7$ J, peak intensity $I \sim 2 \times 10^{19} W.cm^{-2}$

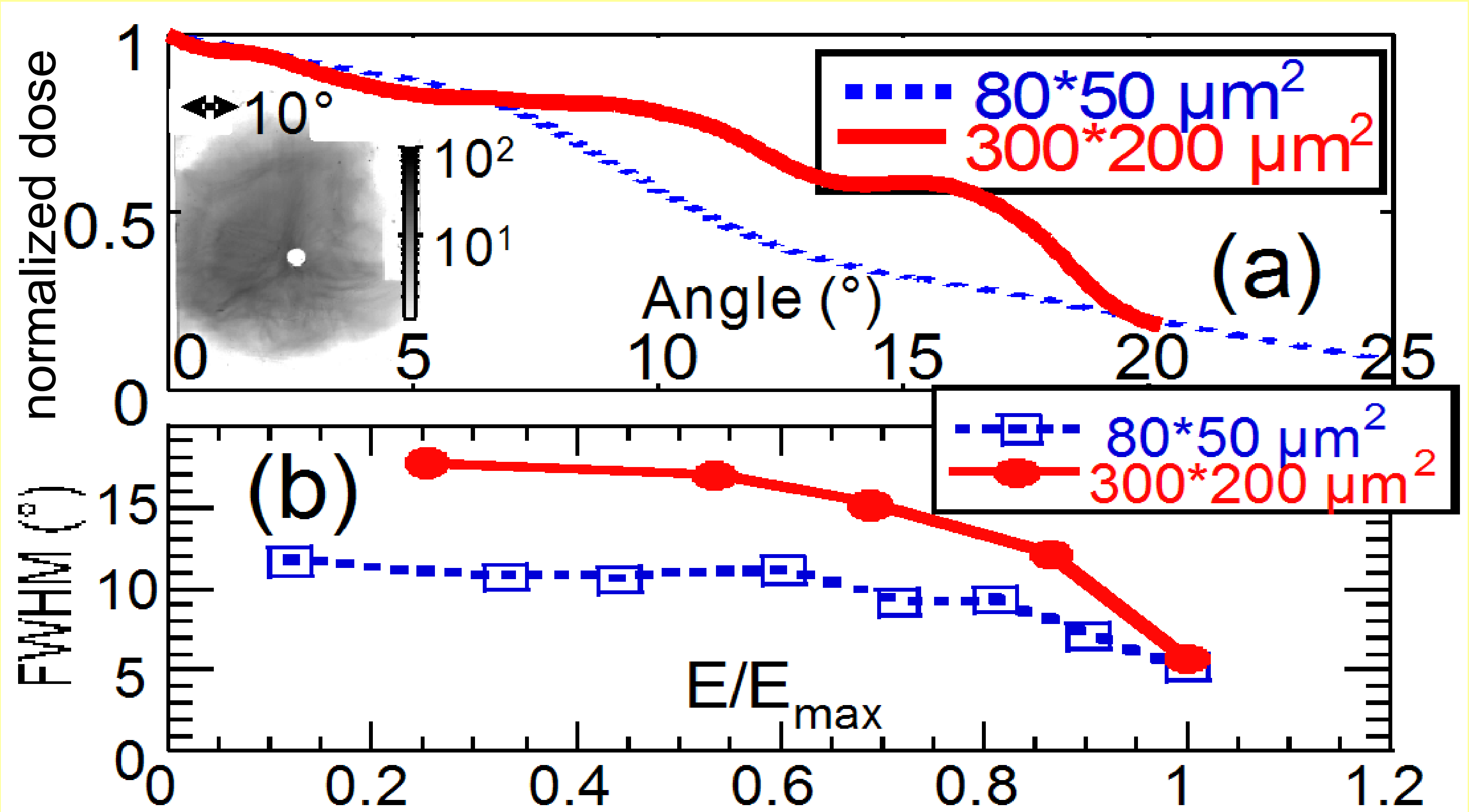
Enhancement of maximum proton energy and laser-to proton energy conversion efficiency

- proton energy and conversion efficiency increases starting from target surface area of ~ 3-4×10^4 μm^2, corresponding to transverse target diameter D_s<170-200 μm
- conversion efficiency calculated for protons with E_k>1.5 MeV



Angular distribution of accelerated protons

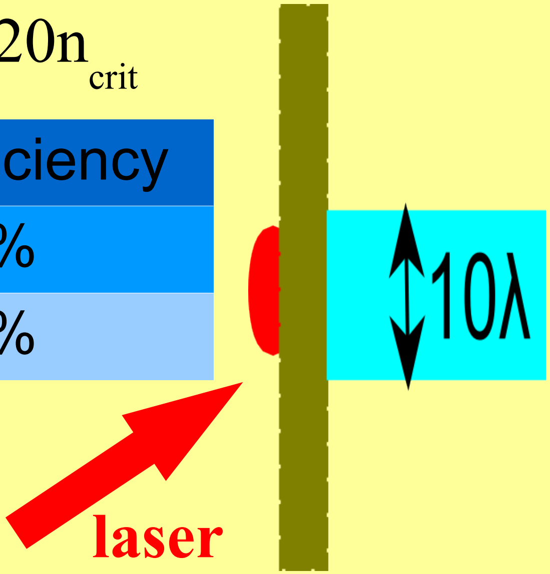
- (a) azimuthally averaged angular proton dose profiles extracted from RCFs and normalized to $E/E_{max} \sim 0.6$ for two targets of different surface area
- (b) FWHM of angular transverse profiles for all proton energies



2D particle-in-cell simulations

Simulation parameters: λ=0.6 µm, τ_L=80 fs, a_0=2.5, n_e=20n_{crit}

	sizes	max. energy	conv. efficiency
smaller foil	20λx2λ	12 MeV	5.5%
larger foil	80λx2λ	10 MeV	3.5%



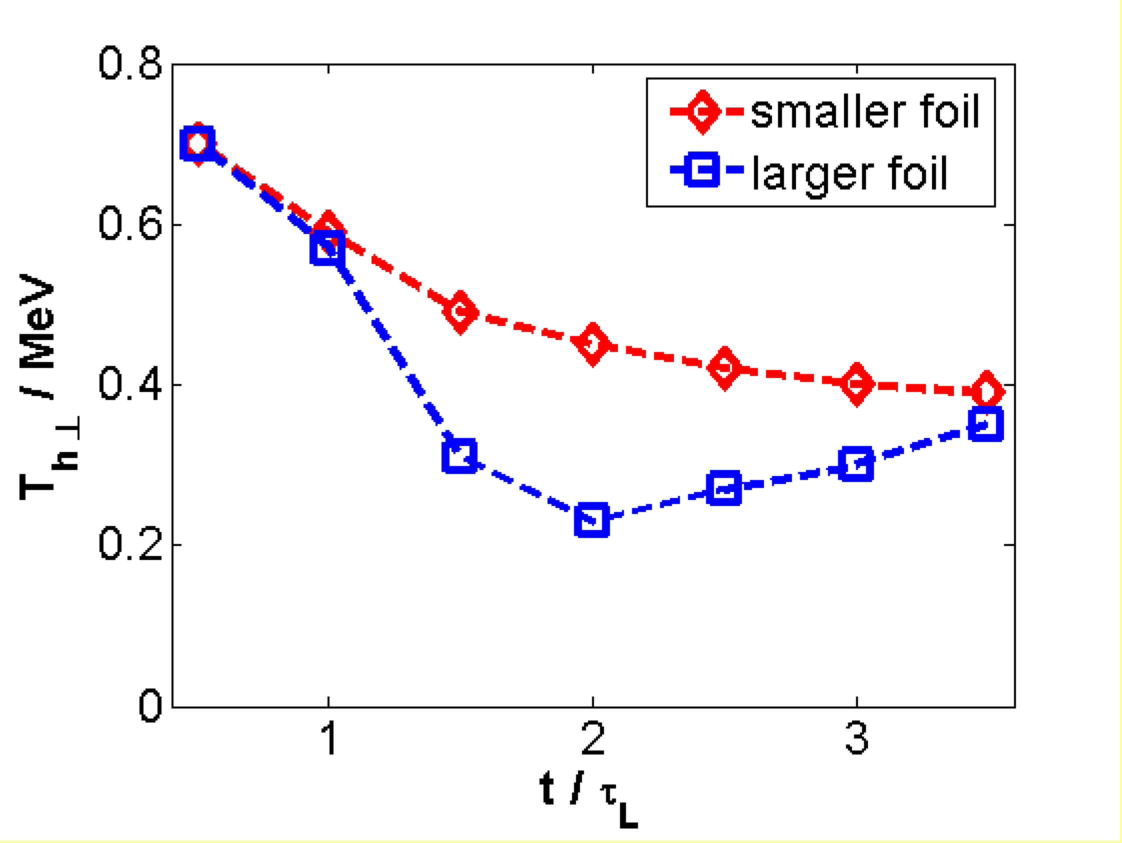


Figure: hot electron temperature component in the perpendicular direction to the target surface derived from simulated energy spectra of hot electrons beyond the laser focal spot in several time moments

smaller vs. larger foil

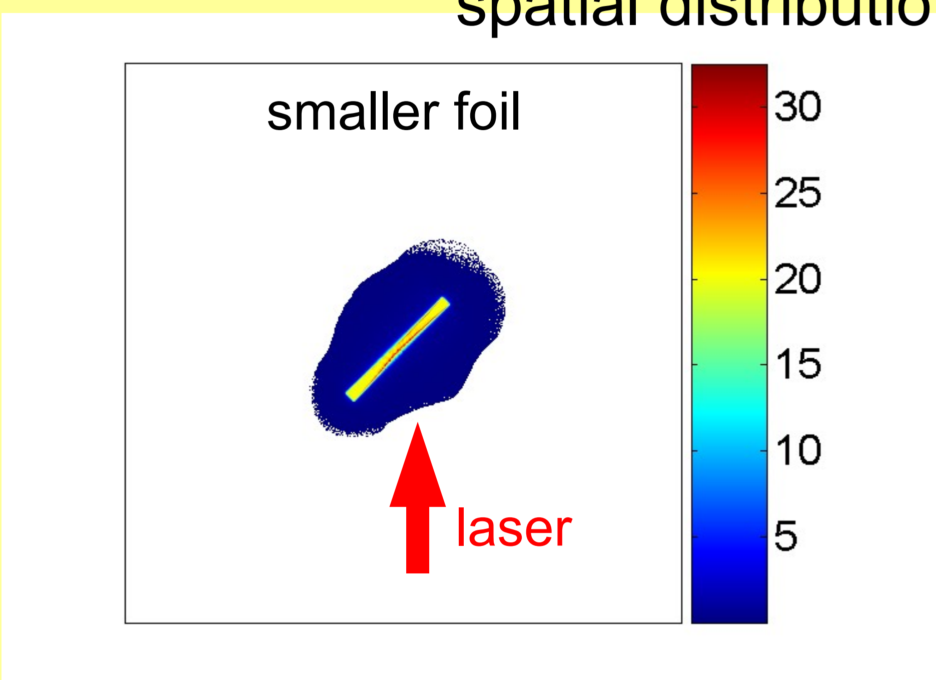
- smaller foil $D_s/(c\tau_L) \approx 1/2$

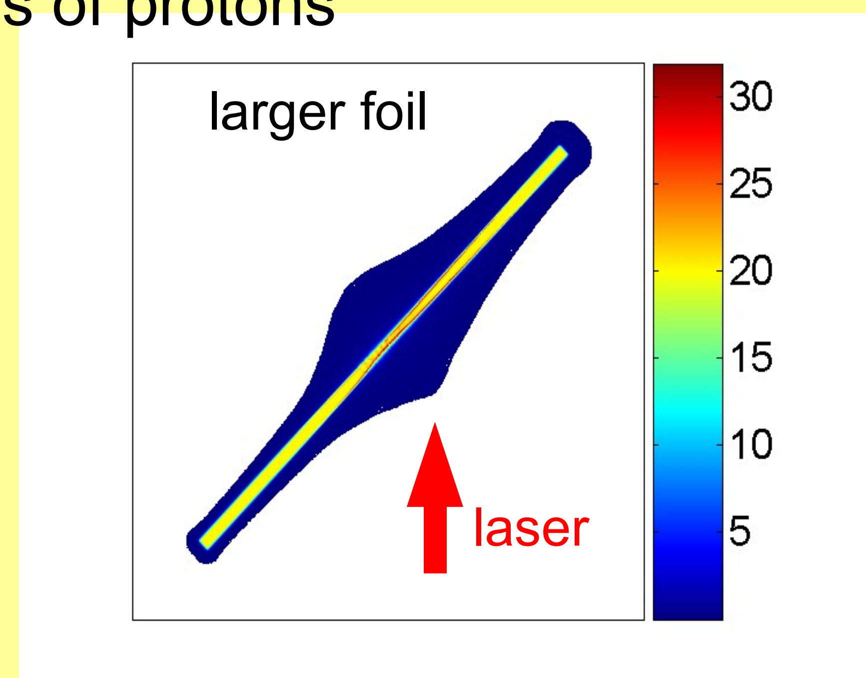
electrons reflected from foil edges mix with newly heated electrons, more homogeneous hot electron sheath

- larger foil $D_s/(c\tau_L) \approx 2$

D_s - transverse target size,
$(c\tau_L)$ - spatial laser pulse length
h – target thickness $h \ll c\tau_L$
v^t_{hot} – average transverse spread velocity of hot electrons
$v^t_{hot} \approx 0.7$ c (≈ 0.2 μm/fs)

spatial distributions of protons





Conclusions

- experiment at LULI (foils of the same thickness and various surface)

  – threefold increase of the maximum energy, increase of the conversion efficiency about an order of magnitude

  – proton beam divergence is reduced about two times

- PIC simulations

  – the increase in maximum energy and conversion efficiency is due to hot electrons reflected back from foil edges which mix together with newly accelerated electrons behind the laser focal spot

  – the acceleration of protons is more uniform in the case of smaller foil due to more homogeneous hot electron sheath

Thank you for your attention