Thickness determination of free-standing nm-targets

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2013

ION ACCELERATION

by laser plasma
interaction with nm-foils

LASER CONTRAST

Development of Plasma Mirror, XPW

>> from thin to ultra thin foil targets

>> higher ion energys

>> new acceleration mechanisms

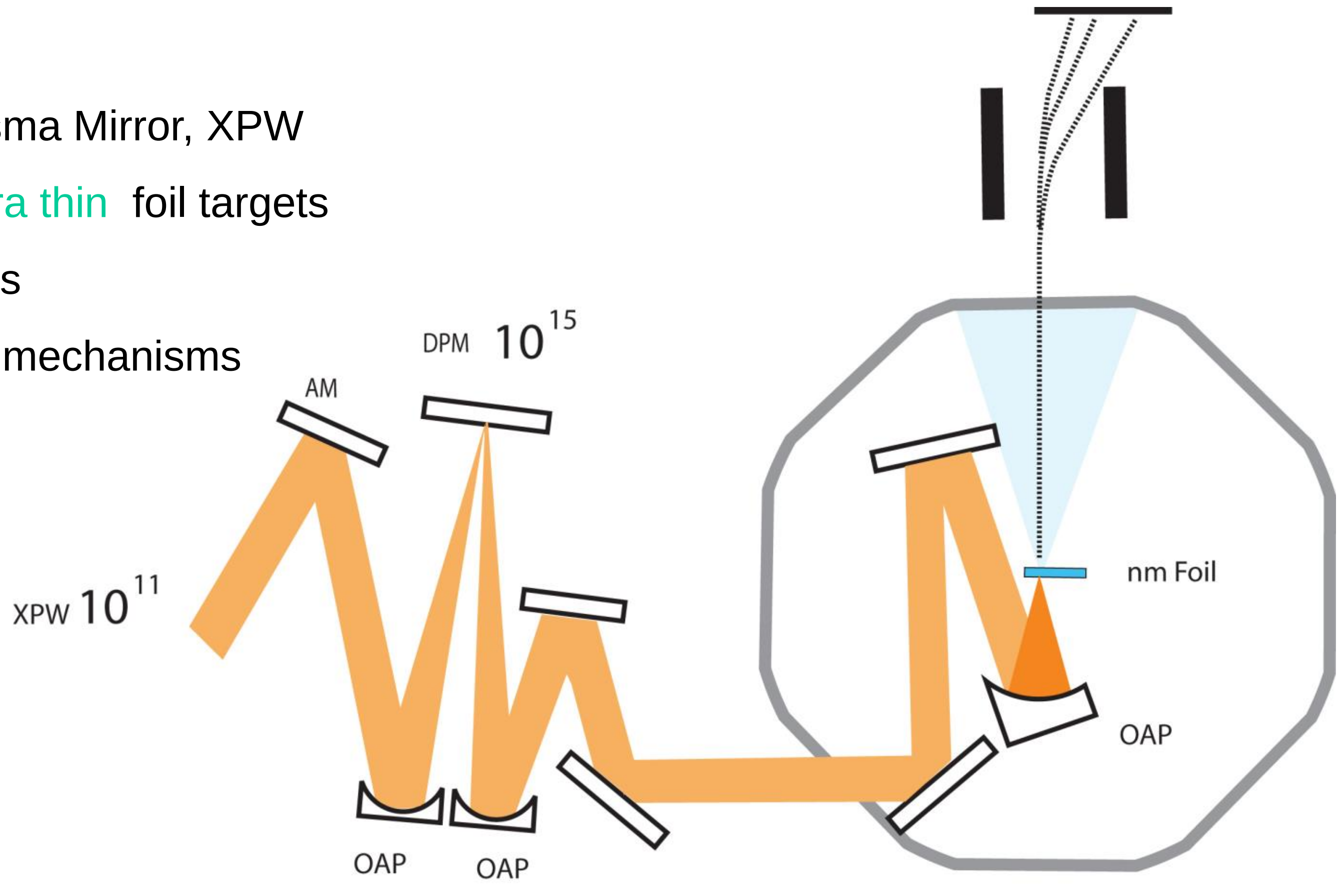
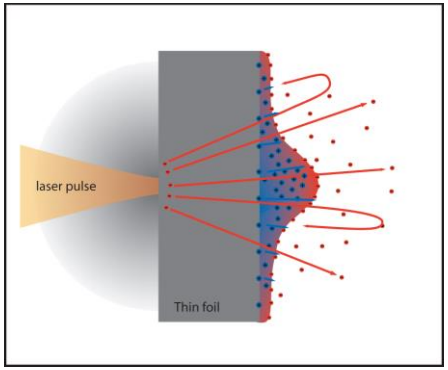


Table of content

TNSA (Target Normal sheath acceleration)

- Capacity model
- Acceleration of contamination layer



Enhanced TNSA

Thinner targets enhance TNSA mechanism by less energy-loss for the recirculating electrons

BOA (Break out Afterburner)

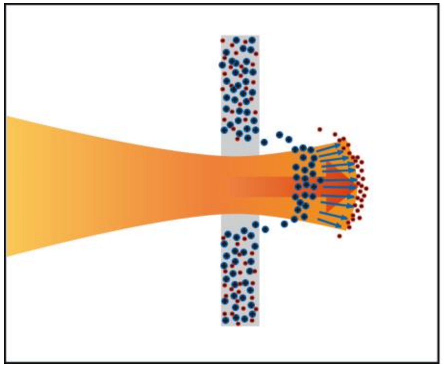
Thickness ~ skindepth transparent for laser

Enhanced hot electron production in forward direction

RPA Radiation Preassure Acceleration

Pressure of light accelerates electrons,

Pulling ions



RPA-LS Leaky Lightsail - RPA

SCALING PARAMETERS (RPA)

$$a_0 = \sqrt{I\lambda^2 / 1.37 * 10^{18}}$$

$$n_c = 1.1 * 10^{21} / \lambda^2$$

- Density (ne)
- Chemical composition (C:H – ne)
- degree of ionization, transparency…
- Wavelength (nc, a0)
- Intensity (a0)

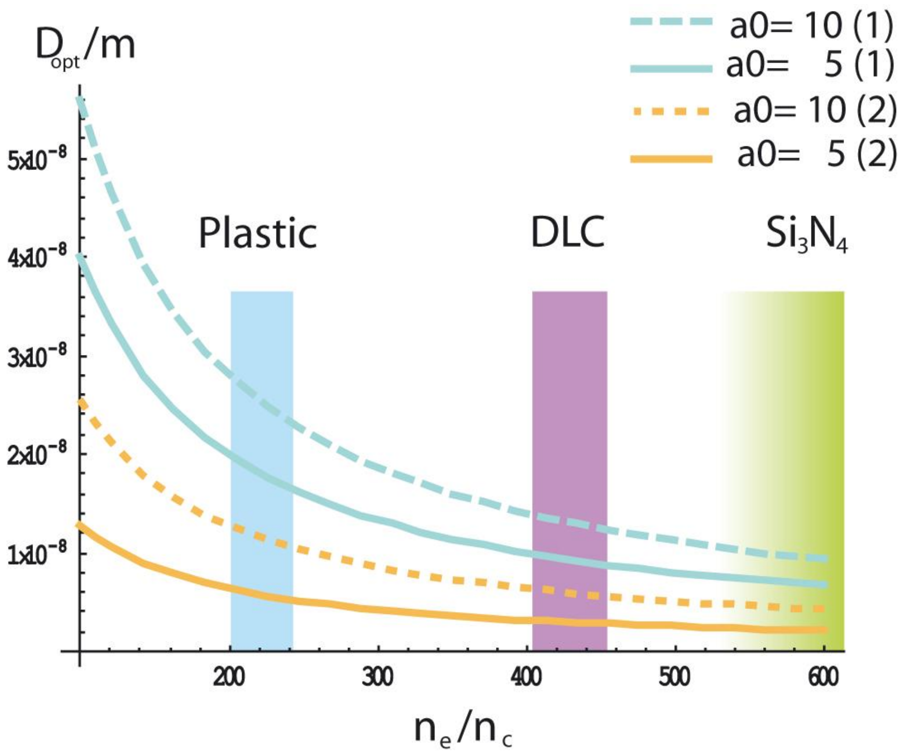
Optimum thickness:

$$d = (3 + 0.4 a_0) \frac{\lambda_L}{n_e / n_c} (1 - R)$$

Esirkepov, PRL 96, 105001, 2006

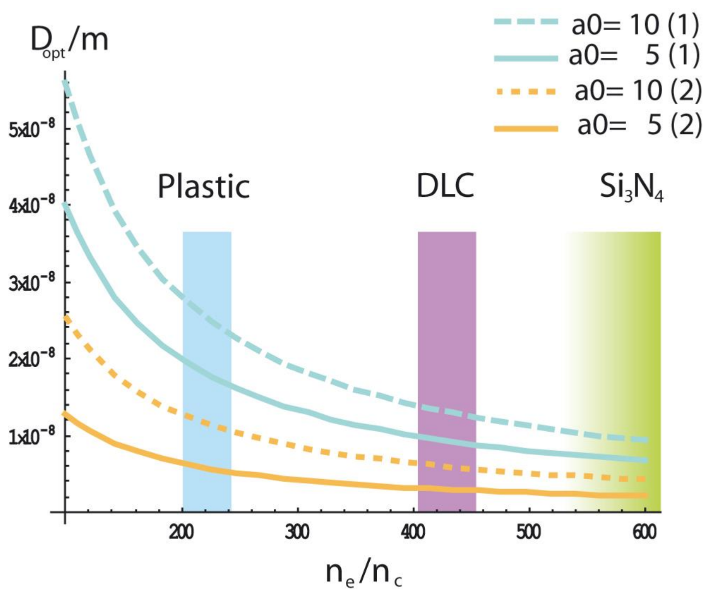
$$d = a_0 \frac{\lambda_L}{\pi n_e / n_c} (1 - R)$$

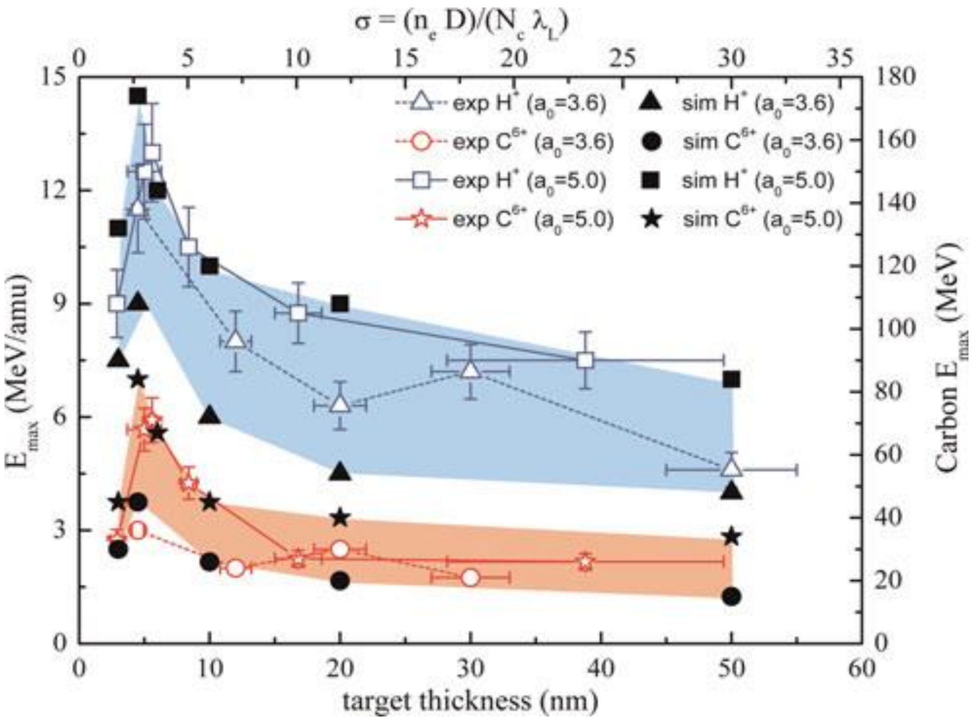
Macchi, 10.1103/RevModPhys.85.751, 2013



$\lambda = 0.8 \mu m$

Target thickness scan



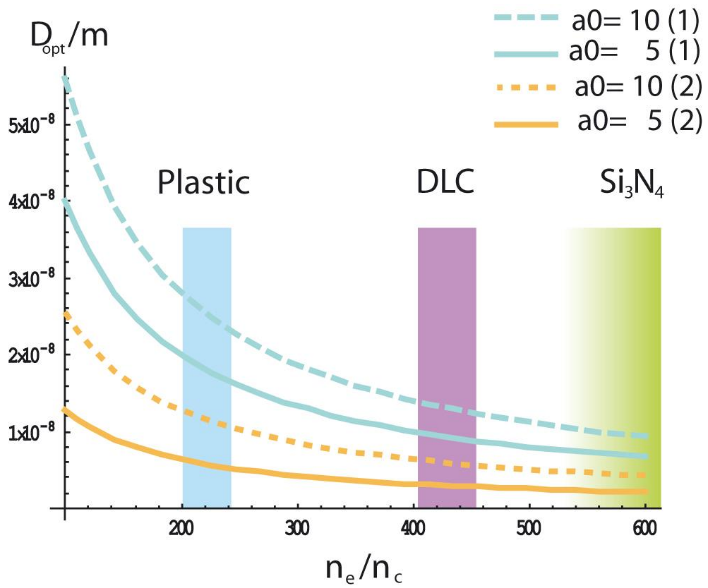


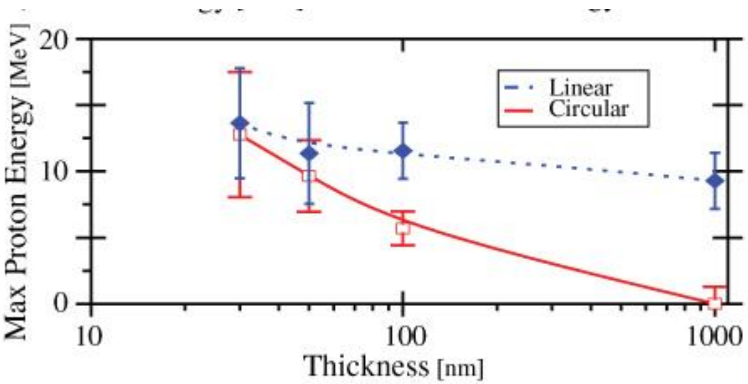
DLC, a0=5 @ 45fs, 800nm

MBI, lin

Steinke, Laser Part. Beams, 28, 2010
Henig, PRL 103, 2009

Target thickness scan



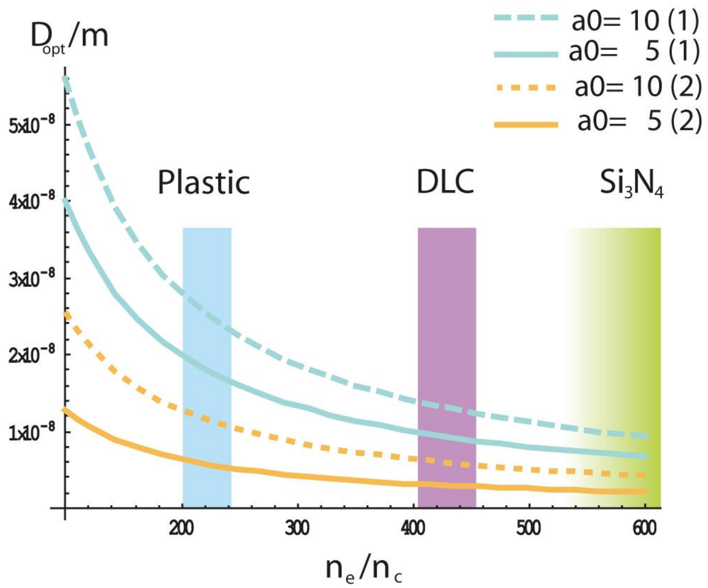


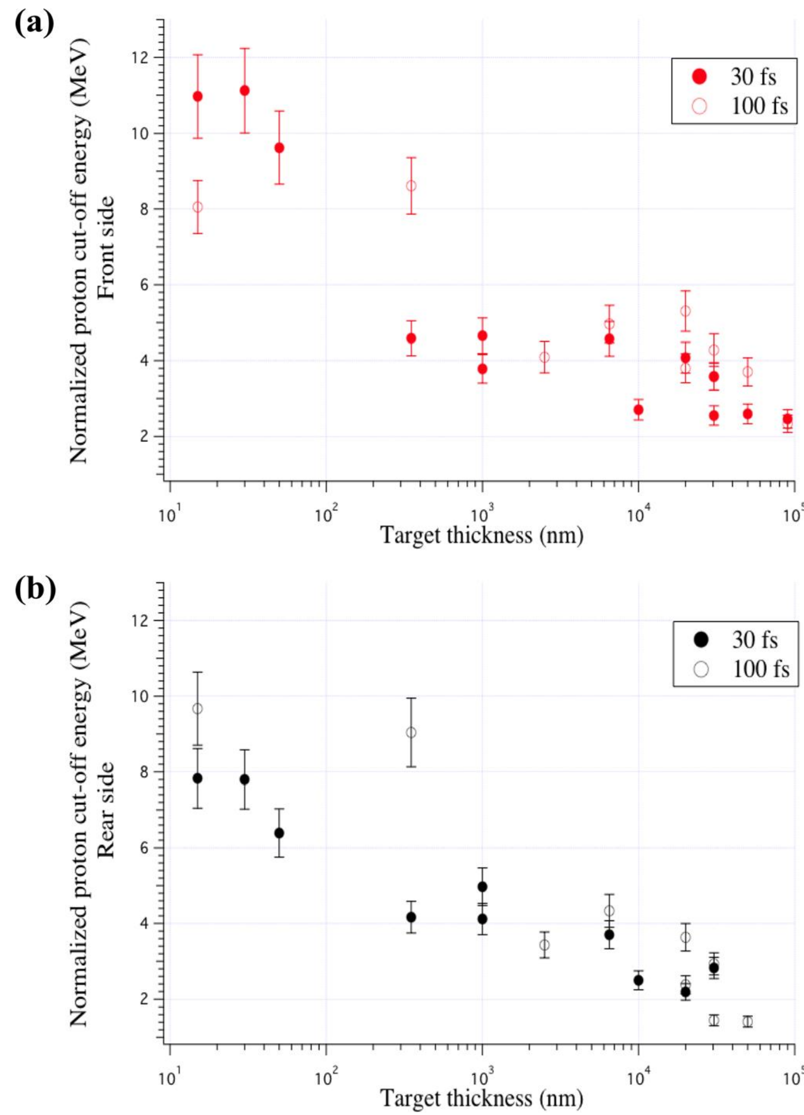
Si3N4, a0=30 @ 40fs, 800nm, 1.5 J

HERCULES

Dollar, PRL 208, 2012

Target thickness scan





45°, 1.8J, 8.5*10^20 W/cm^2,

ALLS at INRS-EMT

Al, Al-Si3N4 foils

Fourmaux, PhysPlas 20, 2013

thickness determination

Height sensitive Methods

- Atomic force microscope
- Confocal microscope

Optical methods

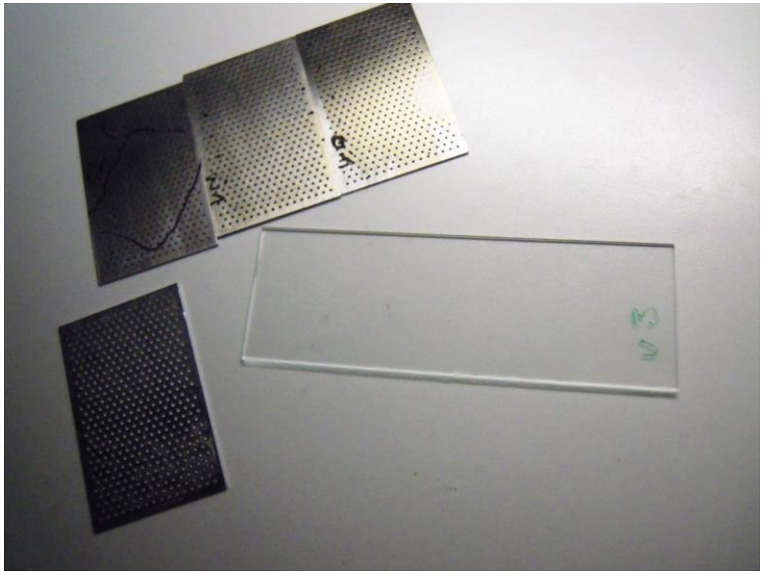
- Ellipsometry
- Transmittance

Measurement of foil
on a plane substrate

Step like boundary (cut)

Metal substrate (plane)

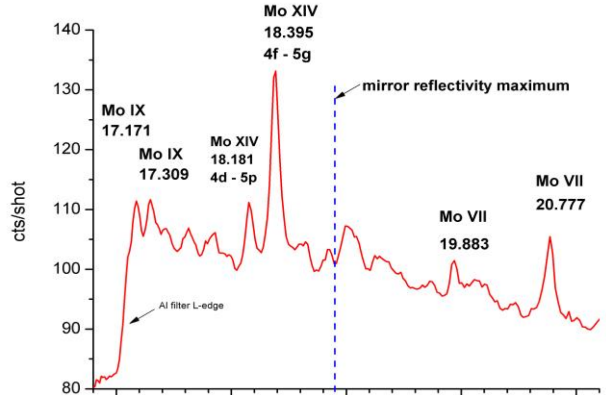
Free standing Foil



EUV source characteristics

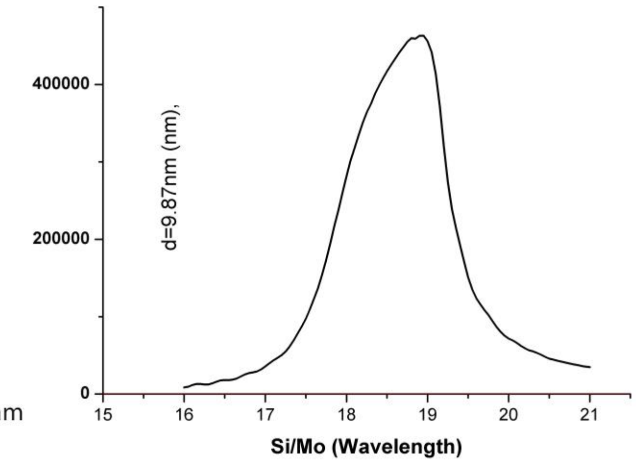
- Incoherent plasma radiation from Mb
- 4° Mo/Si multi-layer mirrors act as monochromator @ $18.9 \pm 0.5\ nm$
- High photon-flux

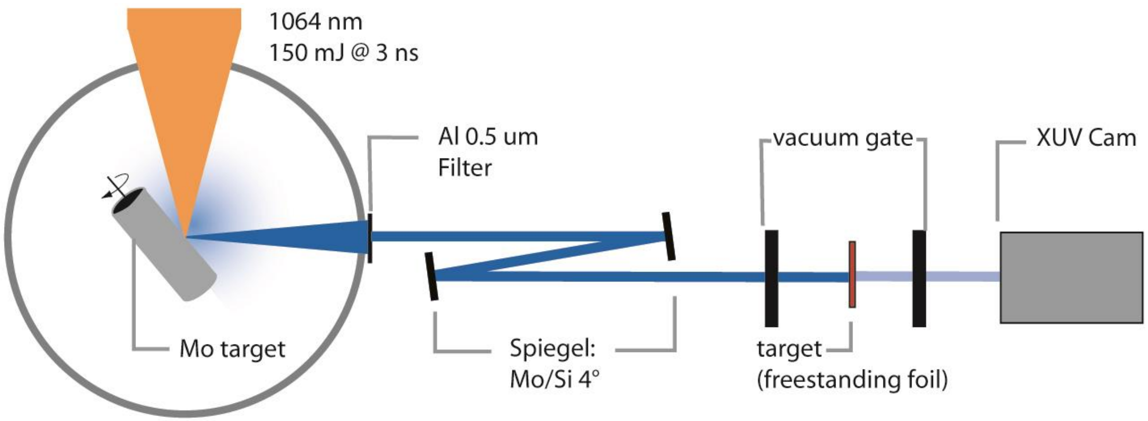
$8 \times 10^{4}\ photons / s\ @\ 15\ mm^{2}$



Advantages:

- Reversible measurement of T
- through a freestanding foil
- Fast method





Mantouvalou, Rev.Sci.Instrum. 8, (2011)
Braenzel, Rev.Sci.Instrum. 84, (2013)

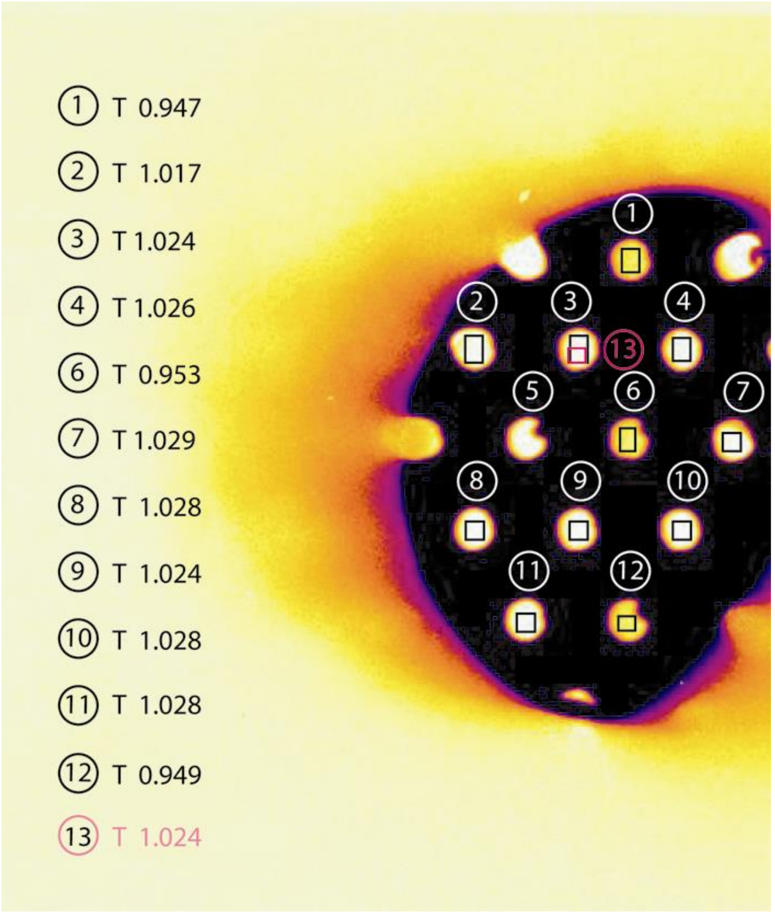
Tranmittance measurement

- 21 shots per measurement
- High accuracy for Transmittance

  $\Delta T = 0.005$ (100%=1)
- Comparison of foil`s transmittance with transmittance of uncovered holes
- Averaging over (< 300um x 300 um)
- Change of absorptions over one foil covered hole

From transmittance to thickness:

- Stochiometry and density is needed
- Calibration with a thickness reference



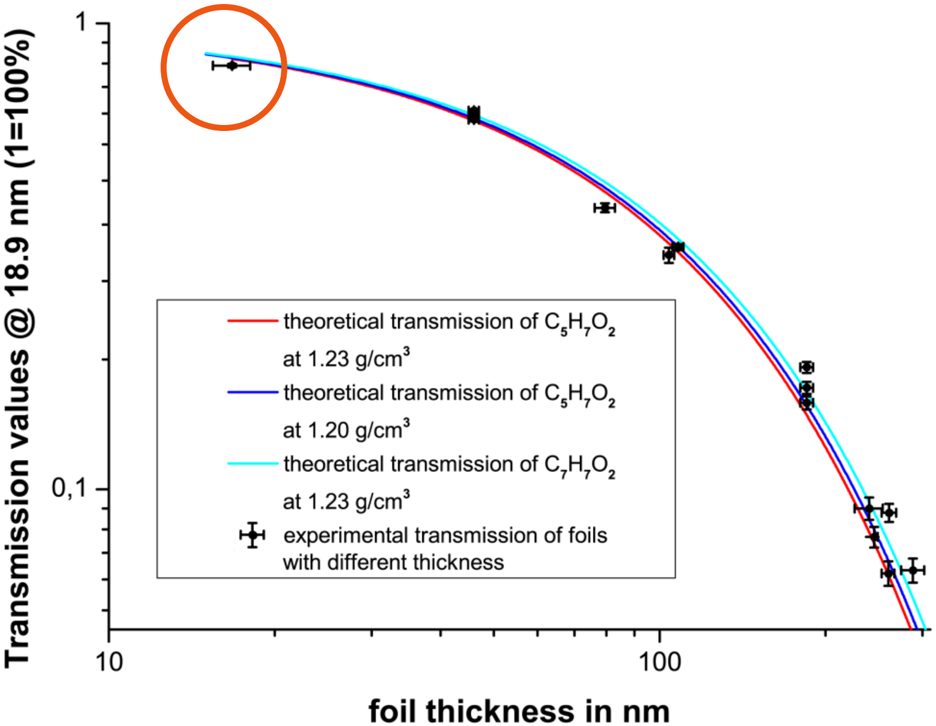
Transmittance measurement of ~ 6nm plastic foil.

At holes (1),(6),(12) the foil had been removed, to use it as a T=100% reference.

CALIBRATION

- Cross calibration with a height sensitive Method of same foil (C. Kreuzer, P. Hilz / MPQ / AFM & confocal microscopy)
- @ given density and stochiometry compare experimental derived T values with theory

$\Delta D = 3\ nm$



Observations

- ultra thin foils (D<20nm) difficult to measure with height sensitive instruments
- Foils show thickness gradient caused by the process of manufacturing (e.g. D>100nm)
- thickness determination by transmittance gives thickness with ~3% accuracy
- mapping of foil (homogeneity)

http://henke.lbl.gov/optical_constants/

Braenzel, Rev.Sci.Instrum. 84, (2013)

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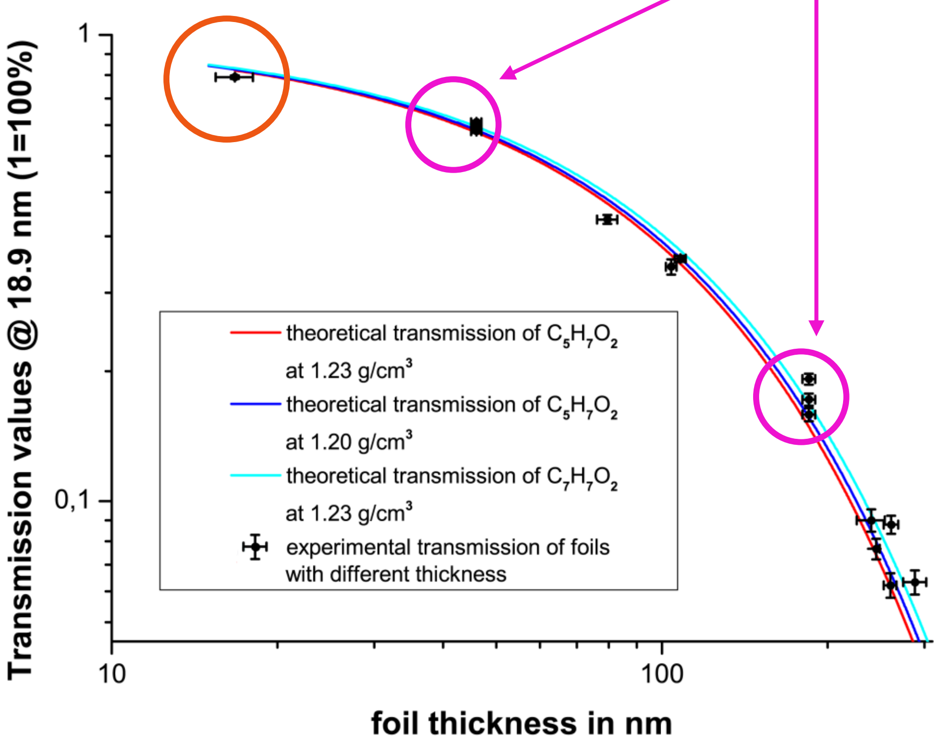
T measurement on different foil areas @ one thickness measurement point with AFM

$\Delta D = 1 - 3\ nm$



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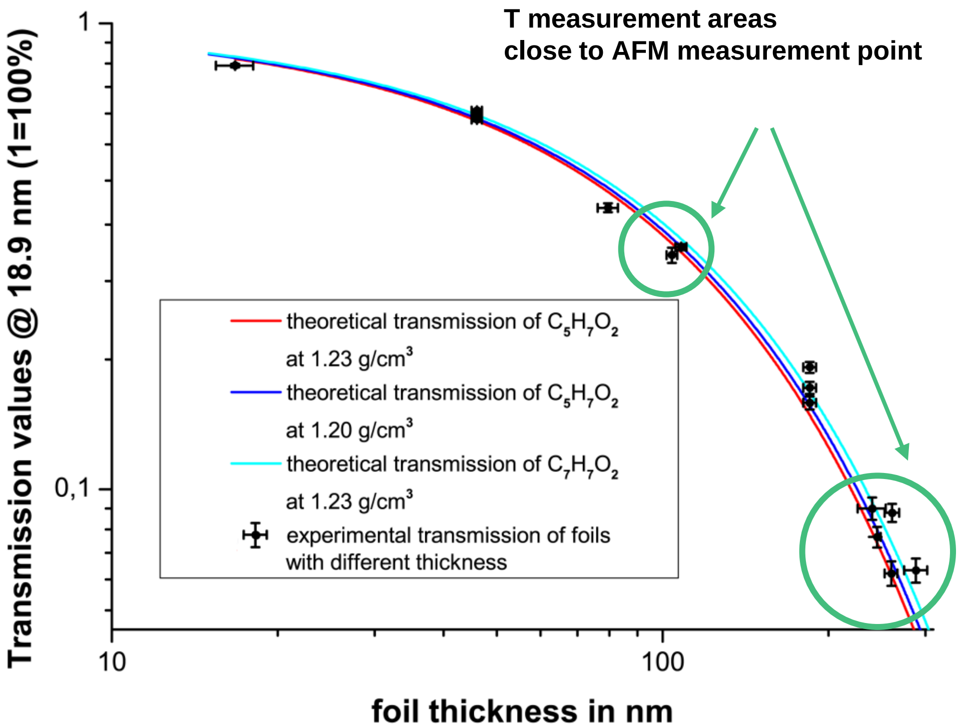


http://henke.lbl.gov/optical_constants/

Braenzel, Rev.Sci.Instrum. 84, (2013)

Parameter Scaling for foil based laser-plasma ion Acceleration

- Experimental results on laser – ion acceleration using ultra thin foils : higher energies
- Careful comparison of each parameter

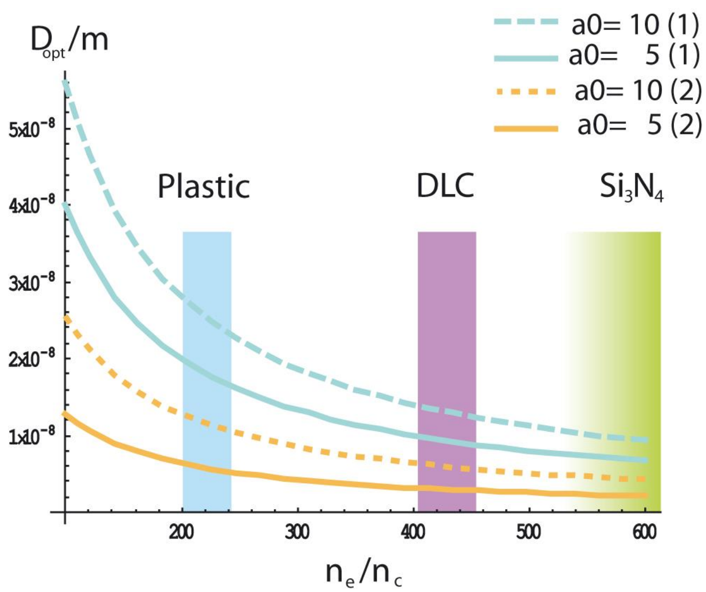
Thickness determination of nm foils

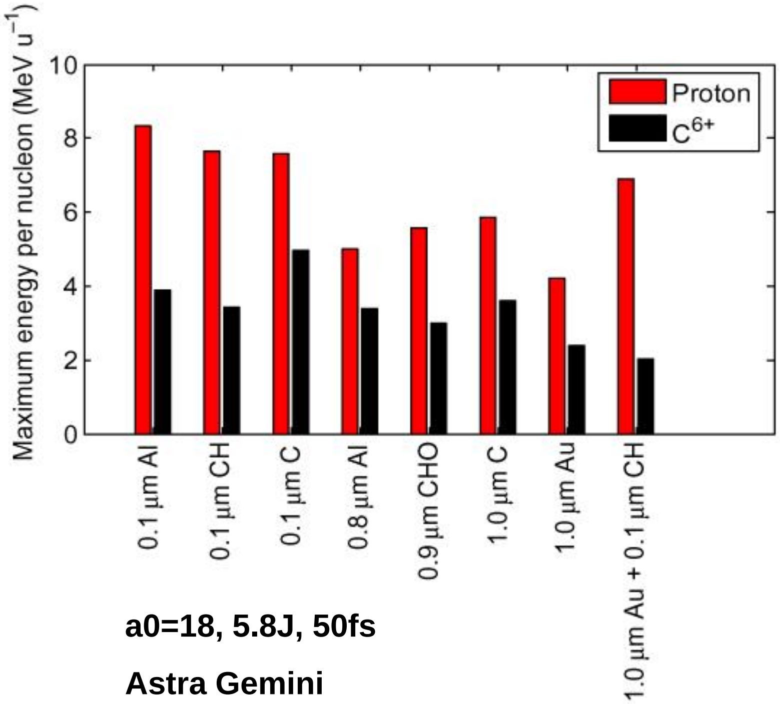
- Suitable method by the transmission values of freestanding foil with high accuracy $\Delta D = 3\%$
- Important parameter for laser plasma ion acceleration
- Towards full control of target properties:
  accurate density measurement
  degree of ionization

THANK YOU FOR

YOUR ATTENTION !

Target thickness scan





a0=18, 5.8J, 50fs

Astra Gemini

Carroll, NJP 3, 2010

Thickness scaling (theoretical)

$$d = \frac{a_0 \sqrt{2}\, \lambda_L}{2\pi n_e / n_c}$$

Qiao,2010

$$d \approx 3.41 * \frac{a_0 \lambda_L}{n_e / n_c} \qquad a_0 \sim \sigma$$

Henig, PRL 103, 245003, 2009

$$d \approx \frac{a_0 \lambda_L}{n_e / n_c}$$

Steinke, PRE 2013

$$d \approx \frac{\sqrt{2}\, a_0 \lambda_L}{n_e / n_c}$$

Macchi, 10.1103/RevModPhys.85.751, 2013

$$d \approx \frac{a_0 \lambda_L}{\pi n_e / n_c}$$

Esirkepov, PRL 96, 105001, 2006

$$d = (3 + 0.4 a_0) \frac{\lambda_L}{n_e / n_c}$$

Transparency

Transparency

Steinke, Laser Part. Beams, 28, 2010
Vshivkov, PhysPlas 5, 1998

Increase of nc in relativistic regime

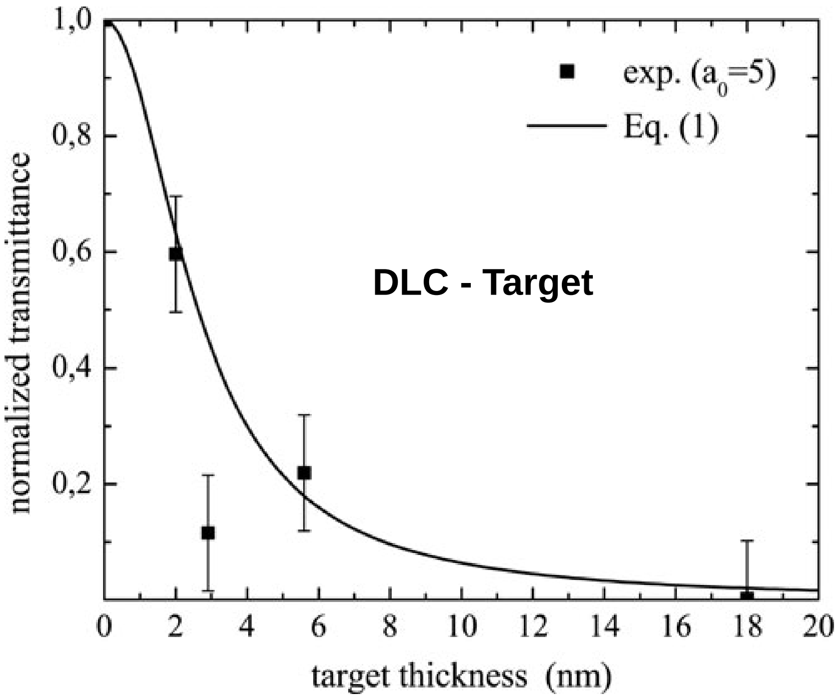
$$n_c = 1.1 * 10^{21} \gamma / \lambda^2$$

$$T = \frac{1}{\left[1 + (\pi\sigma / \gamma_P)^2\right]}$$

$$\sigma \approx \frac{n_e D}{n_c \lambda_L}$$

$$n_e = \frac{\zeta \times Z}{m_{ION}}$$

$$l_s = c / \omega_P = \sqrt{\frac{4 \pi n_e e^2}{m_e}}$$



TNSA?

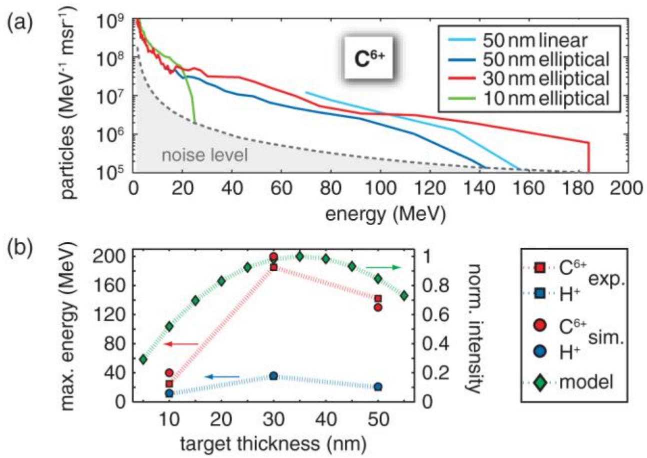


FIG. 2 (color). Observed spectra of fully ionized carbon ions (a) for foil thicknesses of 50, 30, and 10 nm. An optimum in acceleration is seen for the 30 nm target, in excellent agreement with maximum energies of C^{6+} and protons deduced from 1D PIC simulations (b). The normalized instantaneous laser intensity at burnthrough time as derived from the presented analytical model (green diamonds) closely follows the cutoff energy curve.

$$\lambda = 1053 \; nm$$

$$E = 40 - 50 \; J$$

$$\tau_L = 700 \; fs$$

$$I = 7 \times 10^{19}$$

Experiments:

Elliptical pol on DLC foils with some kind of DPM

Claimed contrast (ps) 10^-12

Mechanism:

Transparency regime @ Peakpulse reached
(thermal volume e-heating)

Some formular description – but density only

Out of simulation parameters. (2 Messpunkte!)

Expectations:

Proton energy

Ionen energy cutoff C+6 = 180 MeV

Scaling

Divergence

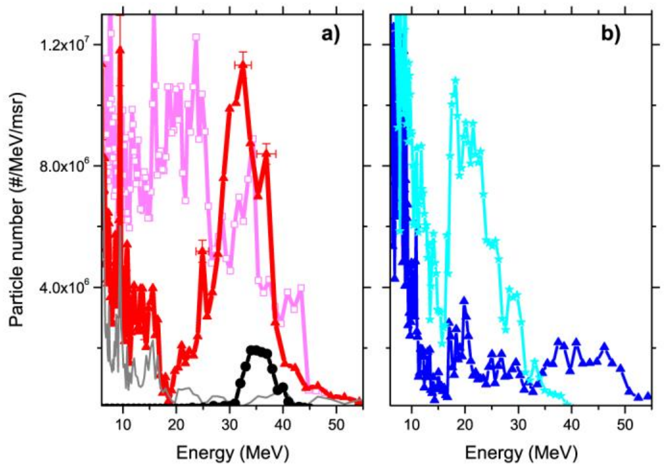


FIG. 2 (color online). (a) C^{6+} spectra measured with CP (red triangles, noise in gray) and LP (magenta squares) from a 5 nm DLC target and the C^{6+} spectrum obtained from 20 μm Pd, published in Hegelich *et al.* [15]; (b) C^{6+} spectra measured with CP from two different shots on 10 nm DLC showing deterioration of the monoenergetic structure at increased target thickness.

$$\lambda = 1054\ nm$$

$$E = ???$$

$$\tau_L = 500\ fs$$

$$I = 2 \times 10^{20}$$

$$\sigma = \frac{n_e}{n_c}(D/\lambda_L) \propto a_0 \qquad \sigma_{ex}(DLC) = 3 + 0.4 \times a_0$$

NOT RPA – Transparency???

Comparism

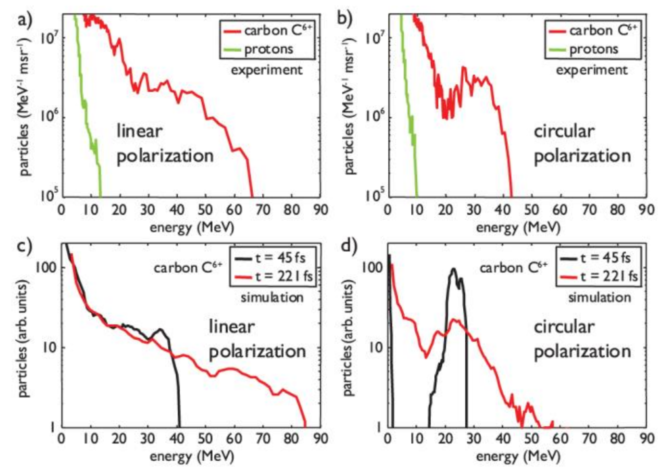


FIG. 2 (color). Experimentally observed proton (green curves) and carbon C^{6+} (red curves) spectra in the case of linear (a) and circular (b) polarized irradiation of a 5.3 nm thickness DLC foil. The corresponding curves as obtained from 2D PIC simulations (c),(d) show excellent agreement with the measured distributions at late times (red curves, $t = 221$ fs after the arrival of the laser pulse maximum at the target). A quasimonoenergetic peak generated by radiation-pressure acceleration is revealed for circular polarization, being still isolated at the end of the laser-target interaction (black curve, $t = 45$ fs).

TNSA?

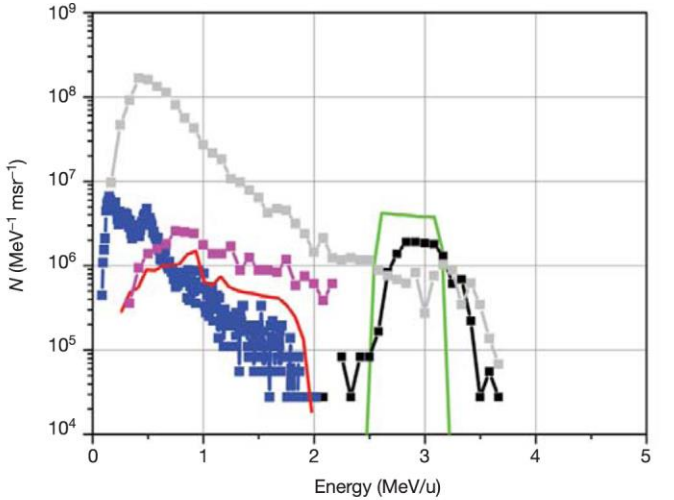


Figure 2 | Monoenergetic carbon ions from a 20 μm palladium substrate. The curves show ion number (N) over energy per nucleon (MeV/u). The black curve shows the spectra of the measured C^{5+} ions, the blue curve shows the dominant substrate charge state Pd^{22+}. The green and the red curves are simulations obtained using the 1D-hybrid-code BILBO, showing the simulated C^{5+} and Pd^{21+} spectra, respectively. The grey curve shows the dominant C^{4+}signal from a heated W target, and the magenta trace shows the C^{5+} signal from a cold Pd target. In these last two cases, the targets have a thick layer of carbon contaminants and do not form a monolayer source. The resulting carbon signals are therefore exponential and show lower numbers in the high-energy range. The errors are: $dN \leq 1\%$ statistical accuracy, and $dE \leq 2\%$ for C and $dE \leq 4.5\%$ for Pd.

$\lambda = 1053 \; nm$

$E = 20 \; J$

$\tau_L = 600 \; fs$

$I = 1 \times 10^{19}$

Experiments: Pd foil with carboncontamination (heated to 1.1 KK = controlled TNSA, Monoenergetic Peaks at optimum Contamination layer – only simulated)

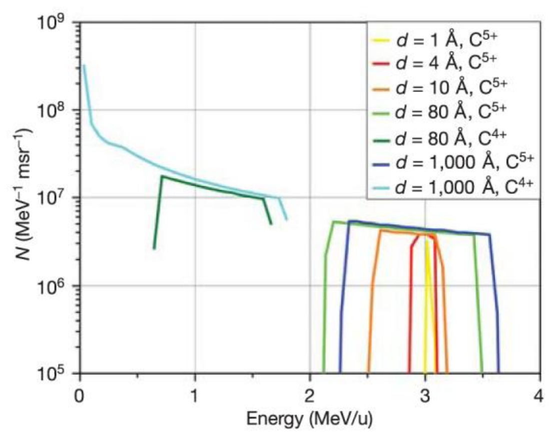


Figure 3 | Changing the thickness of the carbon source layer leads to a change in the energy spectrum in the BILBO simulations. Decreasing the layer thickness (d) causes the spectrum to become more monoenergetic. Increasing the layer thickness leads to a broader distribution and ultimately the appearance of lower charge states and a maxwellian spectrum.

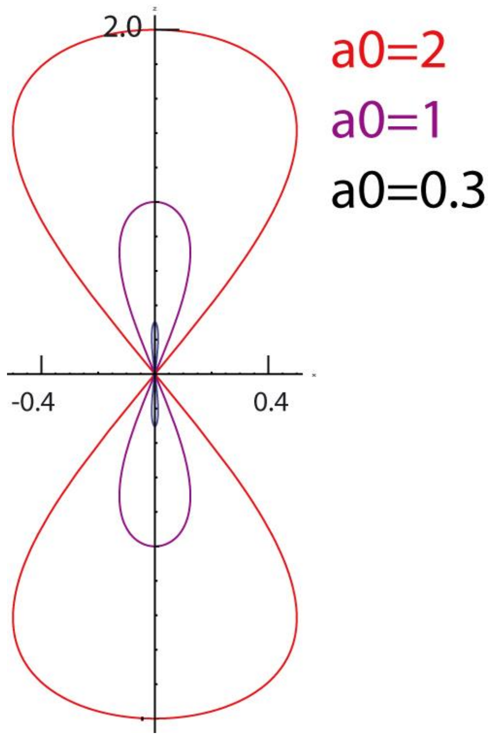
Expectations:

Proton energy

Ionen energy C+5 = 3*12=36MeV

Scaling

Divergence



electron trajectory for a linear polarized EM-wave $a_0 \geq 1$

free electron in EM-Field

$$\vec{F}_L = q(\vec{E} + \vec{v} \times \vec{B})$$

max quiver velocity of electron (classical)

$$v_{max} = \frac{qE_0}{m_e \omega_L}$$

normalized field amplitude

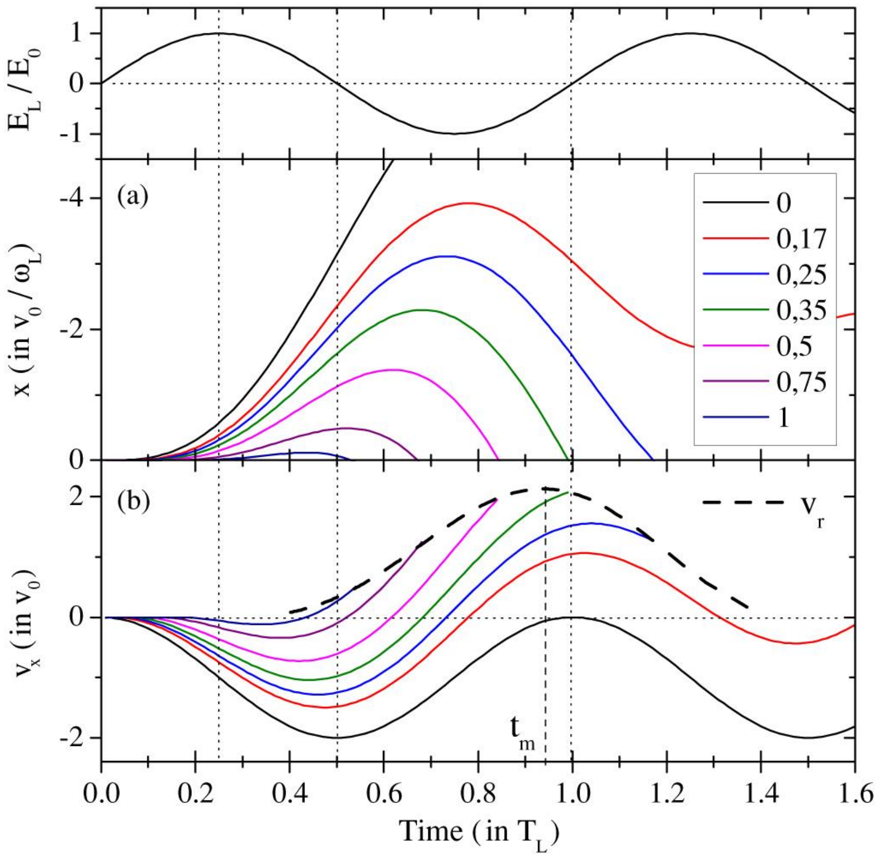
$$a_0^2 = \left[\frac{qE_0}{c m_e \omega_L}\right]^2 = 0.73 \times 10^{-18} I_L \lambda_L^2$$

relativistic intensity for $a_0 \geq 1$

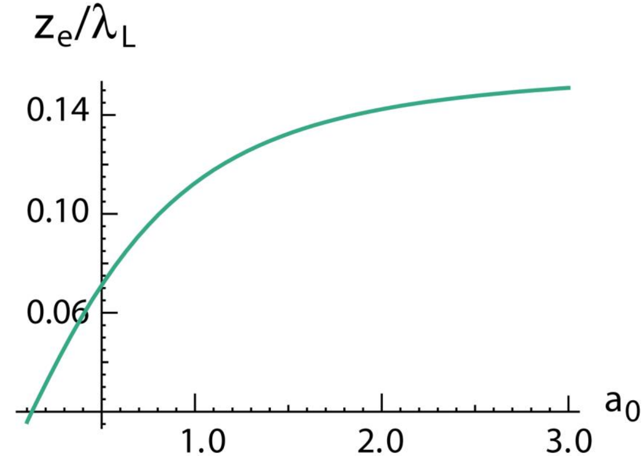
longitudinal electron movement

$$z_e \propto a_0^2 \sin(2\omega_L t)$$

Coherent Wake Emission CWE



t_i time when electron is in vacuum



excursion length of electron quiver velocity due to E field

Thaury, J Phys B, 43 213001, 2010

electrons escaped in vacuum $0.25T_L < t_i < 0.5T_L$
can reenter plasma with high velocity