Enhanced Laser-Plasma Proton Acceleration using foam-attached and Grating Targets

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Collaborators

These experiments are a collaboration with

- Politecnico di Milano Italy
- National Institute of Optics INO-CNR Pisa Italy
- CEA – SPAM Gif-sur-Yvette Frances
- LULI Ecole Polytechnique Paris France
- Czech Technical University, Prague Czech Republic

Target Normal Sheath Acceleration: target design

TNSA well established

- Intense laser pulse on solid foil
- Electron *heating* and expansion
- Sheath field accelerates surface impurities

To improve acceleration

- Laser parameters
- Laser-target coupling

Target design

- Structured, hollowed, curved or multlayer targets improve the ion acceleration
- Issues: stability, cost, reliability, manufacturing

2 designs tested @CEA Paris

- High contrast Ti:Sa laser

1. ***Carbon foam:*** low density + aluminium foil
2. ***Grating:*** plastic foils engraved front surface

FOAM - COVERED TARGET

Nanostructured Carbon foam on Aluminium

FOAM-COVERED TARGETS

Idea:
2 layers target

Low density ***foam*** layer ($\sim n_c$)
on thin overdense plasma

3X

- Improved laser absorption and acceleration

Nakamura *et. al.* Phys. Plasmas (2010)
Sgattoni *et. al.* Phys. Rev. E (2012)

Challenges
foam layer

- Low density $\Rightarrow$ few mg/cm^3
- Adhesion to solid foil
- Robustness to prepulse

Target
manufacture

- @NANOLAB POLIMI: ***Pulsed Laser Deposition***
- Nanostructured Carbon ***grown*** on aluminium

Experimental
results

- Foam withstanded the prepulse
- Within tested intensity $10^{16} \div 3 \cdot 10^{19}$ W/cm^2
  acceleration enhacement @ $I < 10^{18}$ W/cm^2

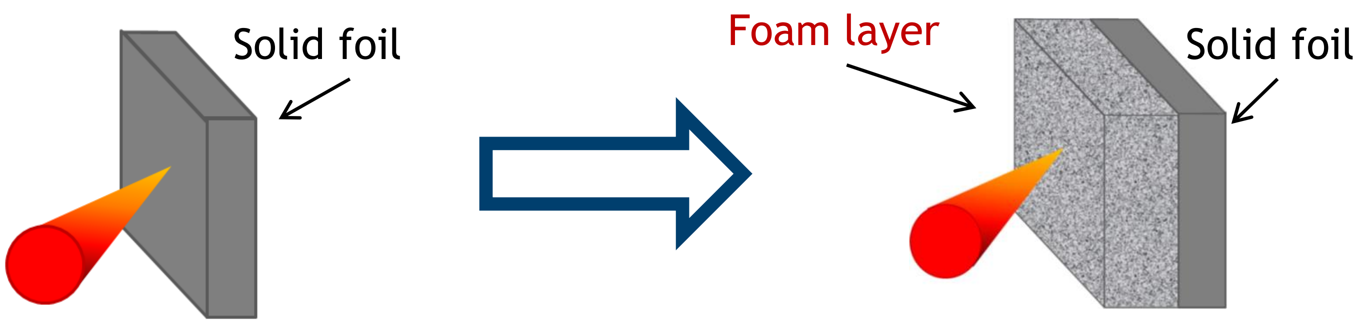
Basic configuration

Proposed target

- near critical plasma $n_e \sim n_c$ $\quad l_f \simeq 1 \div 10\mu\text{m}$
  + thin solid target $n_e \sim 100\text{s}\, n_c$ $\quad l_f \simeq 0{,}5\mu\text{m}$
- Laser-foam: **volume interaction**

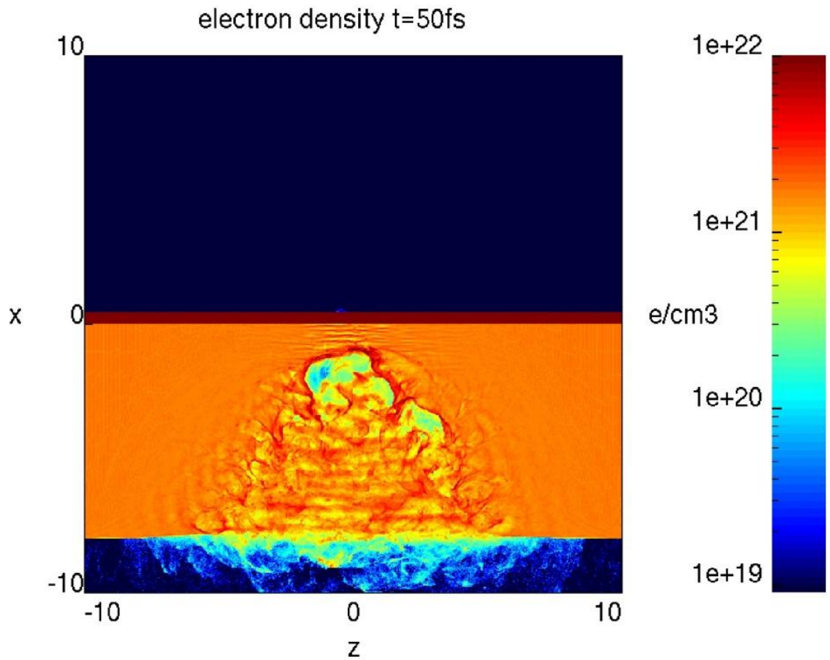
Simulations results $I \gtrsim 10^{19}\,\text{W/cm}^2$

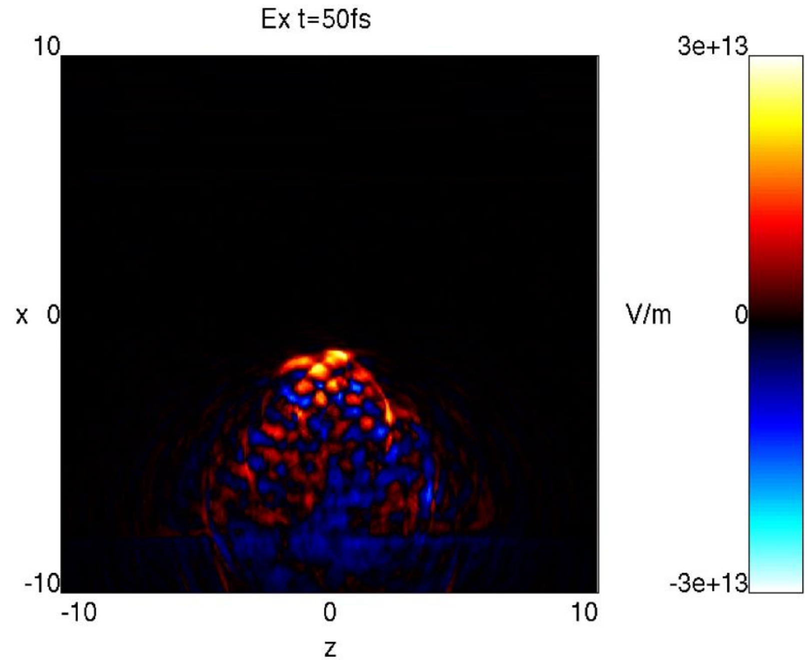
- High absorption $\Rightarrow$ more energetic electrons at higher energies
- Improved acceleration $\Rightarrow$ ${E_p}^{\max}$ up to 3 times higher than simple target

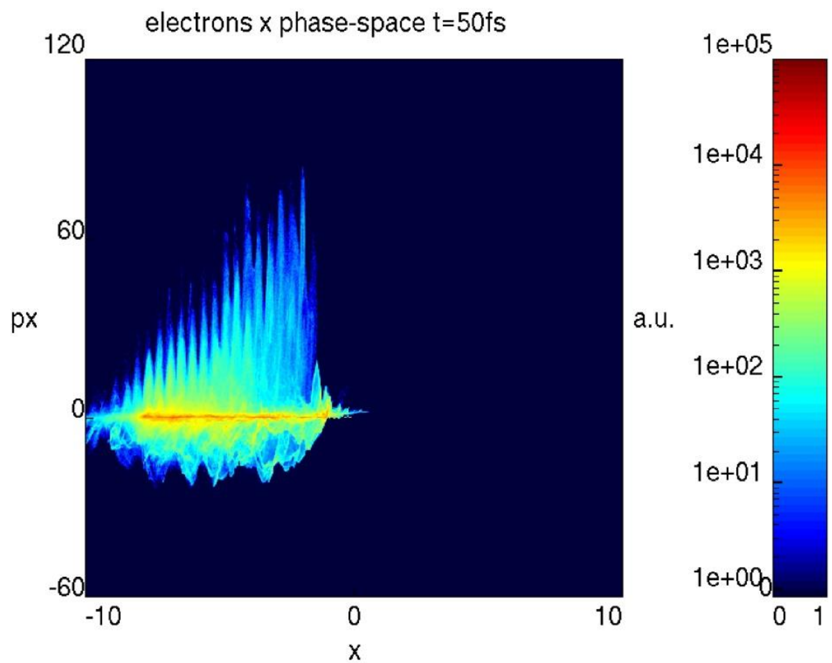


"ordinary" scheme

Foam covered target







2D PIC simulation

Laser:

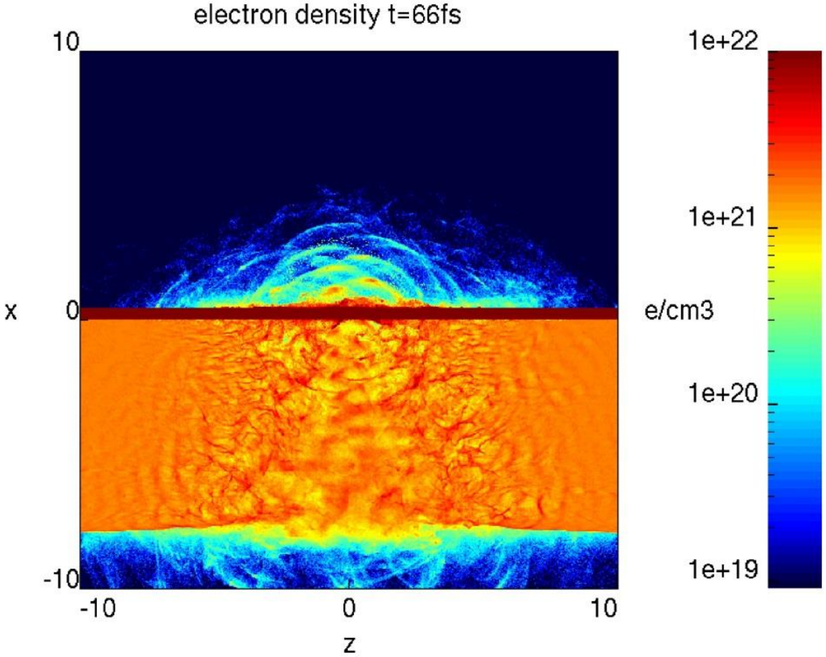
P-pol. $\tau_p = 25\text{fs}$ $a_0 = 10$ $w_0 \simeq 3\mu\text{m}$

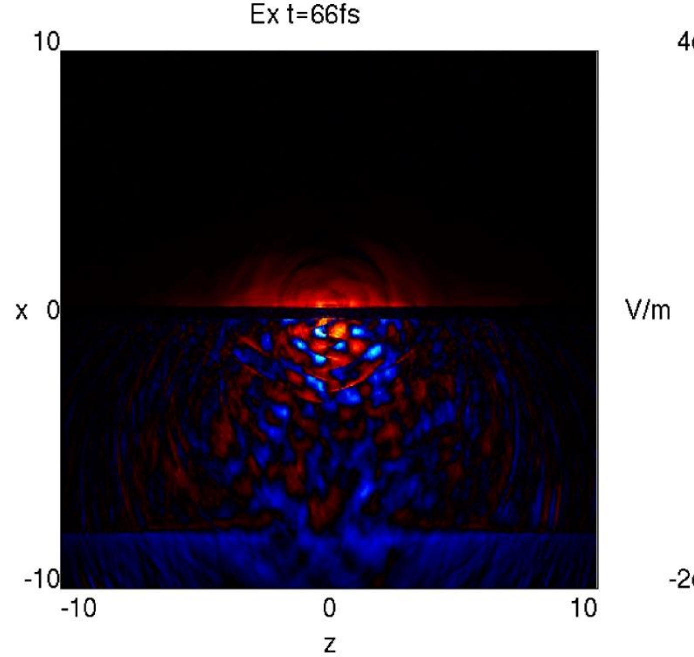
Target:

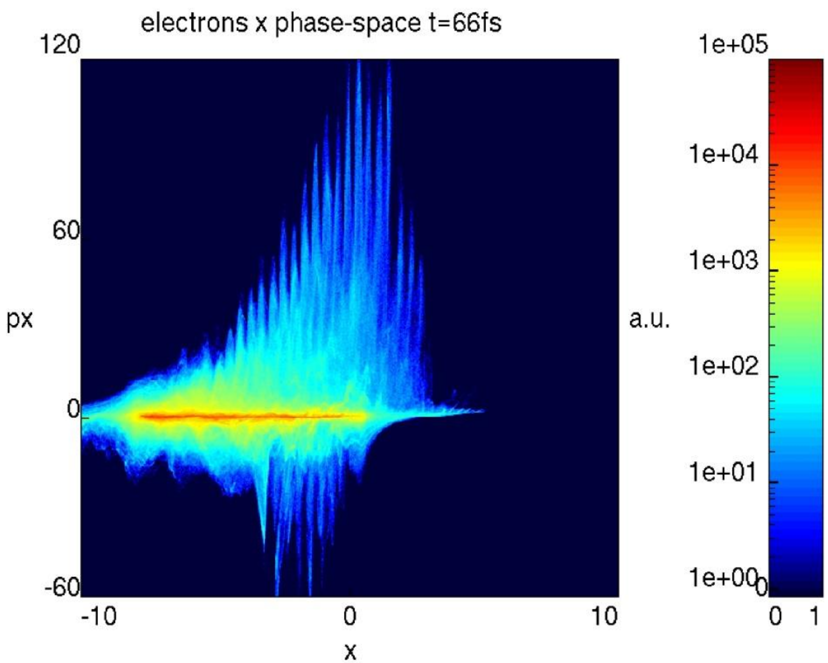
C^{6+} ($8\mu\text{m}, 1n_c$) + Al^{9+} ($0.5\mu\text{m}, 40n_c$)

$+H^{+}$ ($50\text{nm}, 8n_c$)

$$t = 50fs$$







2D PIC simulation

Laser:

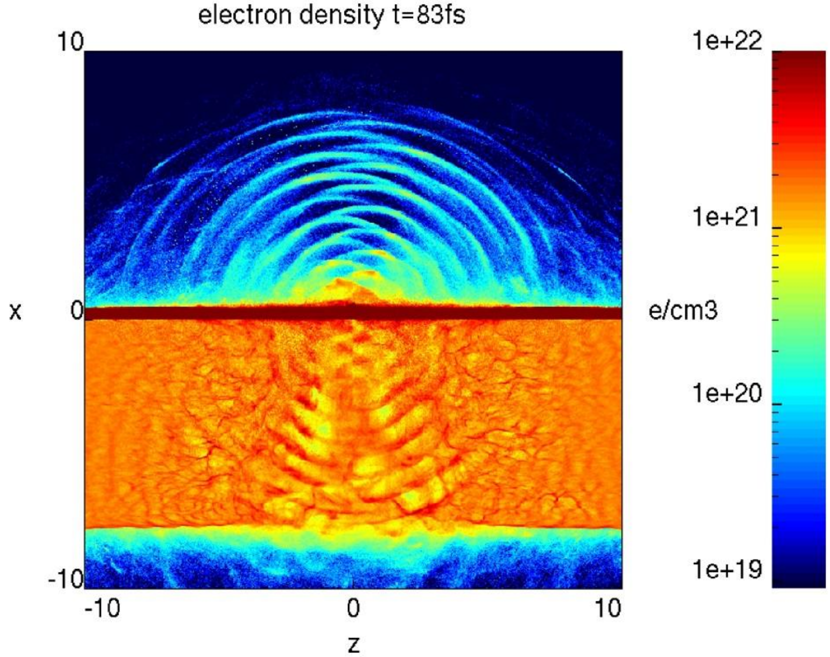
P-pol. $\tau_p = 25\text{fs}$ $a_0 = 10$ $w_0 \simeq 3\mu\text{m}$

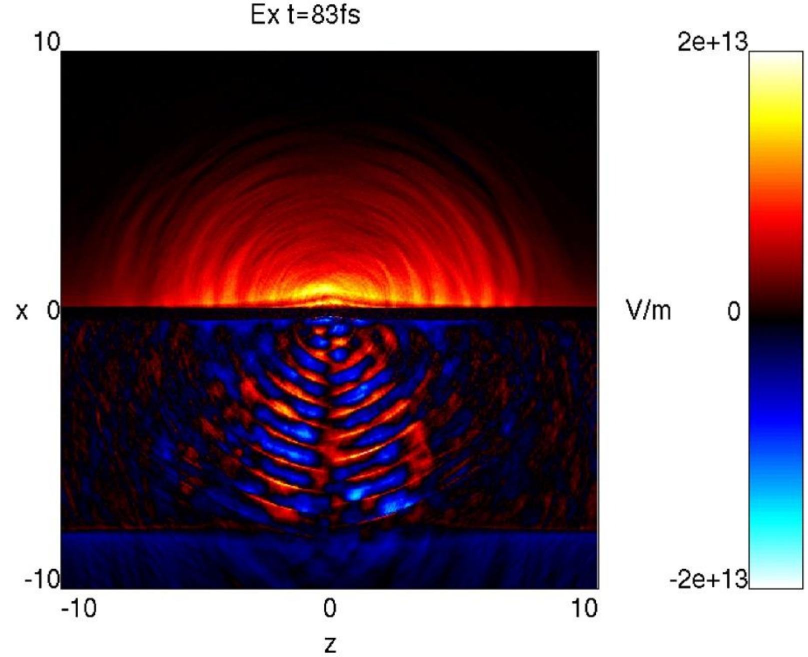
Target:

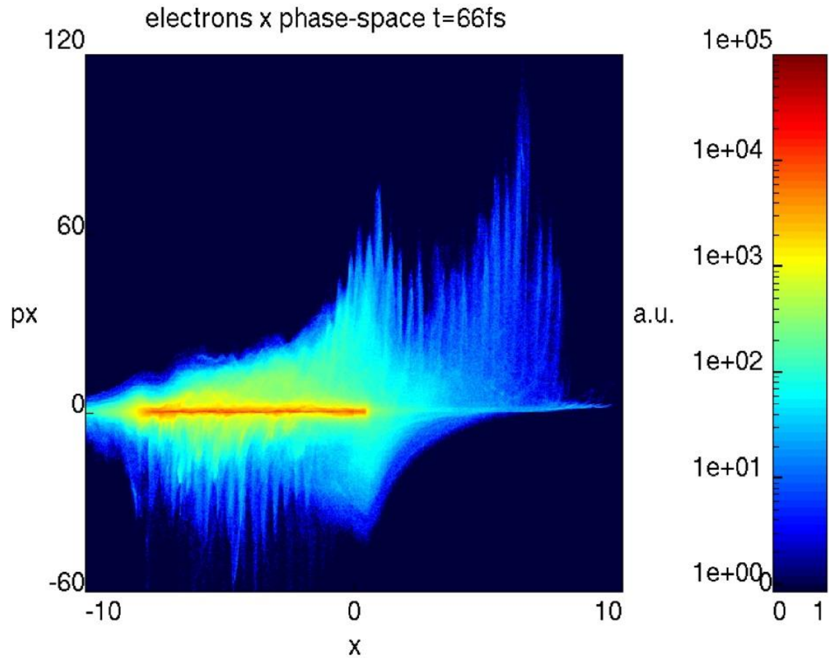
C^{6+} $(8\mu\text{m}, 1n_c)$ + Al^{9+} $(0.5\mu\text{m}, 40n_c)$

+H^{+} $(50\text{nm}, 8n_c)$

$$t = 66fs$$







2D PIC simulation

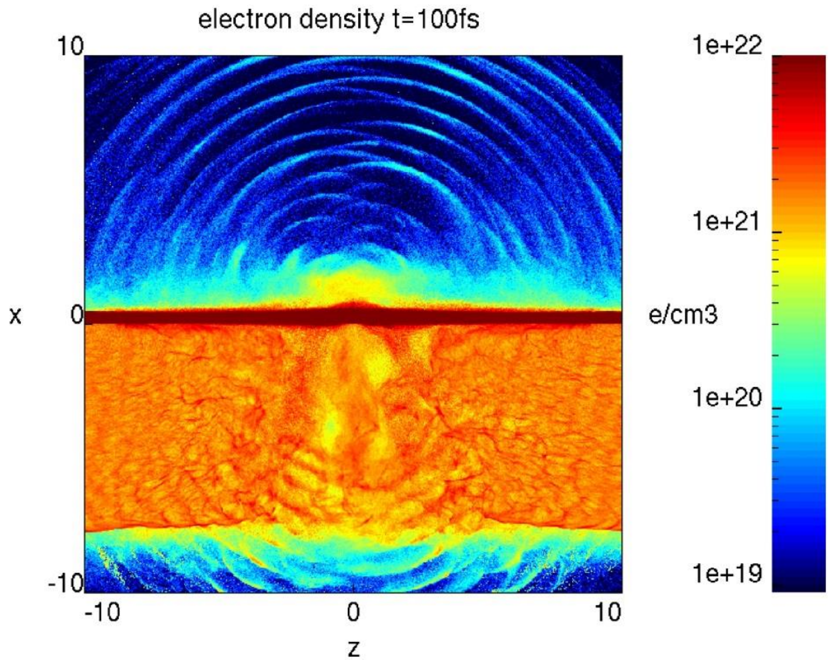
Laser:

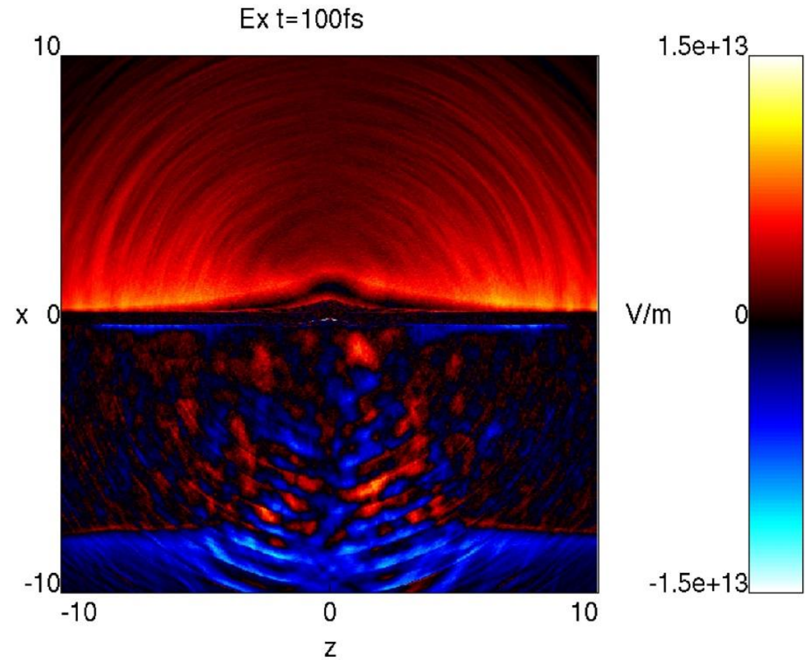
P-pol. $\tau_p = 25\text{fs}$ $a_0 = 10$ $w_0 \simeq 3\mu\text{m}$

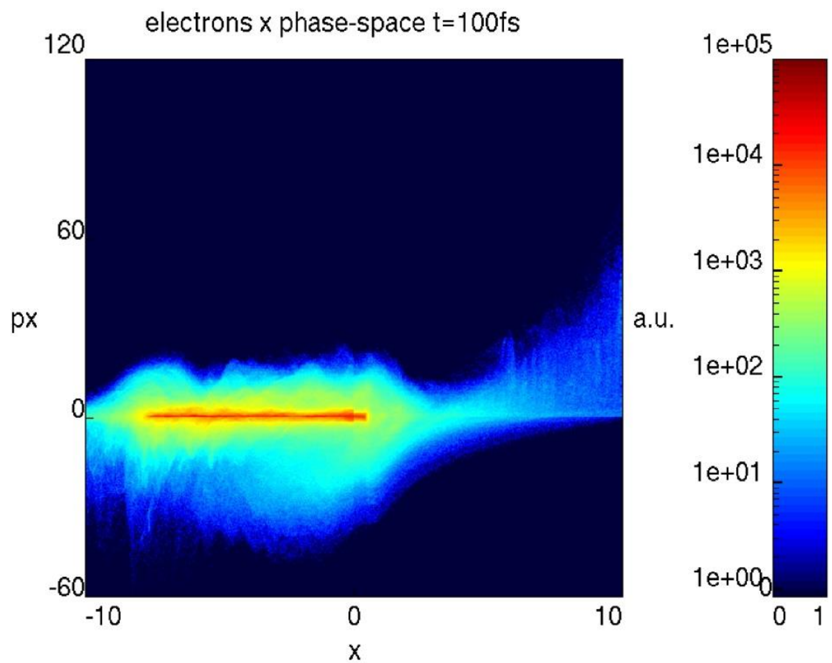
Target:

C^{6+} $(8\mu\text{m}, 1n_c)$ + Al^{9+} $(0.5\mu\text{m}, 40n_c)$ +H^+ $(50\text{nm}, 8n_c)$

$$t = 83fs$$







2D PIC simulation

Laser:

P-pol. $\tau_p = 25\text{fs}$ $\quad a_0 = 10$ $\quad w_0 \simeq 3\mu\text{m}$

Target:

C^{6+} $(8\mu\text{m}, 1n_c)$ + Al^{9+} $(0.5\mu\text{m}, 40n_c)$

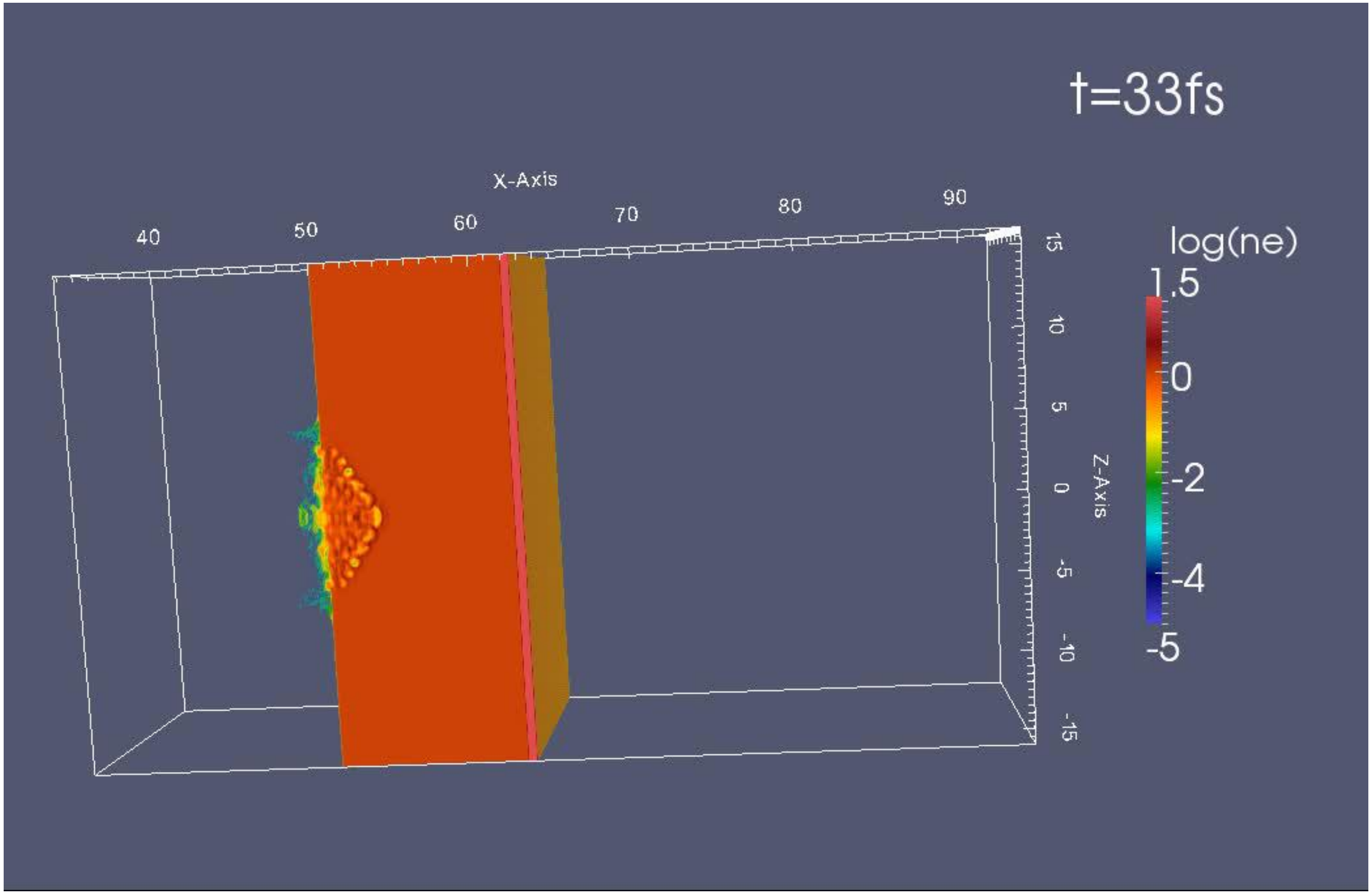
+H^{+} $(50\text{nm}, 8n_c)$

$$t = 100fs$$

3D PIC campaign (in progress)

Laser: P-polarized $\tau_p = 25\text{fs}$ $a_0 = 10$ $w_0 \simeq 3\mu\text{m}$

Target: C^{6+} $(12\mu\text{m}, 1n_c)$ + Al^{9+} $(0.5\mu\text{m}, 40n_c)$ +H^{+} $(50\text{nm}, 8n_c)$



EXPERIMENTAL SETUP @ CEA SACLAY

Laser

P-polarized

- $\tau_p = 25\text{fs}$
- $w_0 \simeq 3\mu\text{m}$
- HighContrast (10^{12}) and LowContrast (10^{8})

$I_{\max} \simeq 3{,}5 \cdot 10^{19}\,\text{W/cm}^2 \quad \boldsymbol{a_0 \simeq 4}$

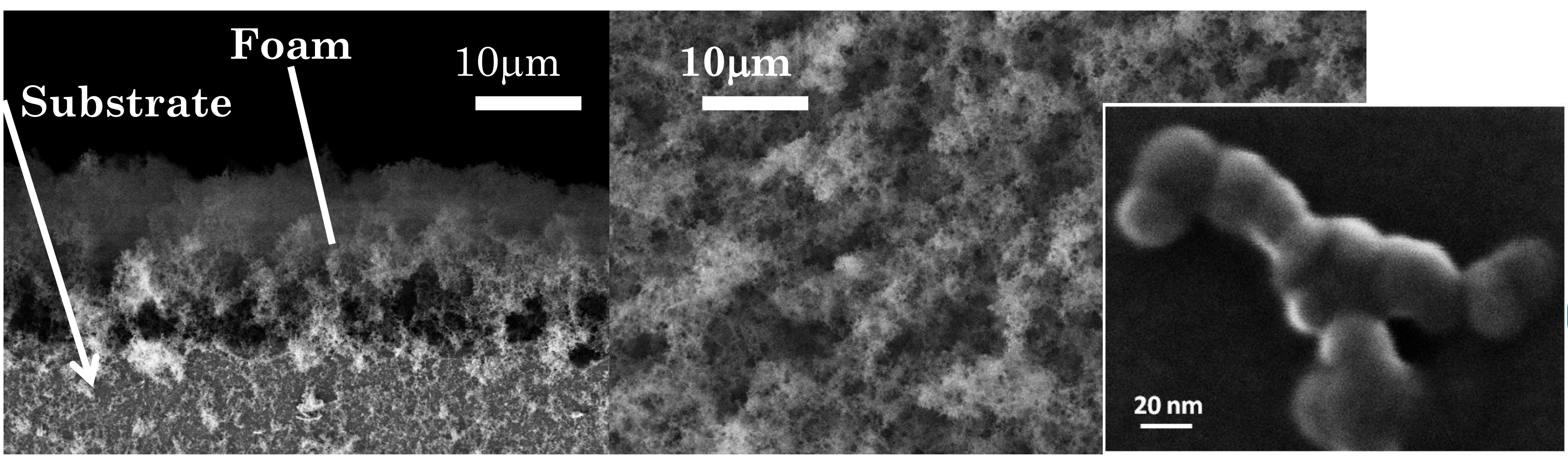
$\theta(\text{incidence}) = 11°$

Target

Nanostructured **carbon foam** $\varrho\sim 5 - 10\,\text{mg/cm}^3$

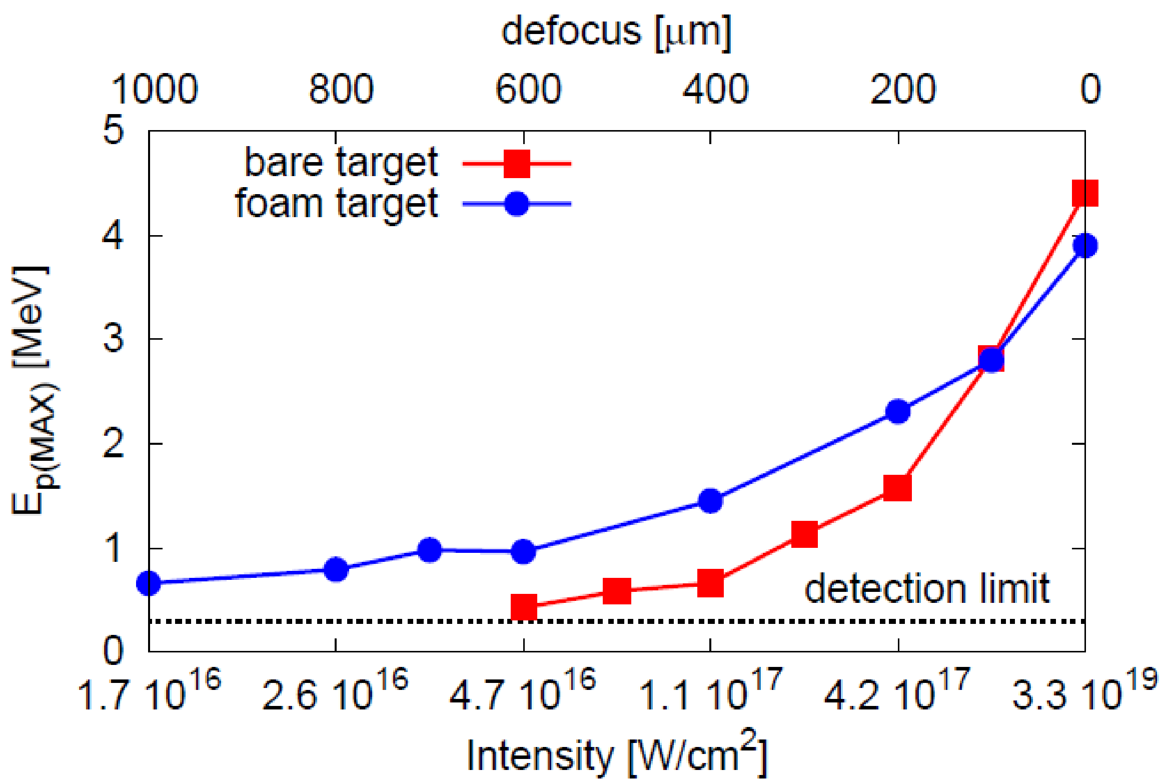
$\boldsymbol{n_f \simeq 1 \div 2n_c} \quad l_f \simeq 10\mu m$

deposited on **aluminium foils**



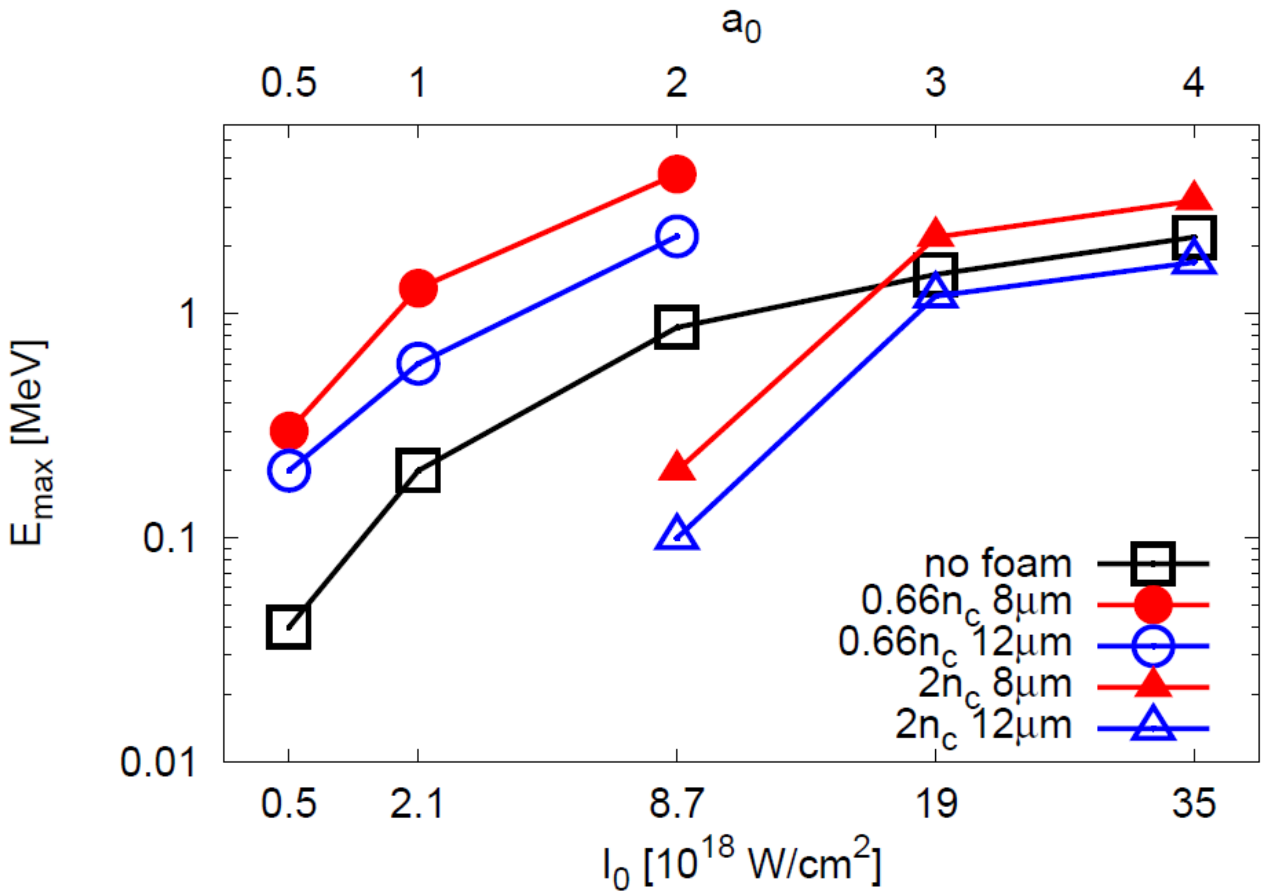
Proton cut-off energy

High Contrast   Al 1,5 μm + 10 μm foam



- At maximum focalization FT similar to ST
- If $I \lesssim 10^{18}\ \mathrm{W/cm^2}$ FT is higher than ST

2D PIC SIMULATIONS



- $a_0 > n_e/n_c$
  FT and ST: similar energy
- $a_0 \sim n_e/n_c$
  laser is reflected by the foam
  ~ no proton acceleration
- Underdense foam
  considerable advantage
  over ST

Foam target: conclusions

New target production

- PLD: production of innovative multilayer targets
- Flexible and reliable at low contrast too

Proton energy enhacement

- Enhanced proton acceleration at moderate/low intensities $I < 10^{18}\ \mathrm{W/cm^2}$
- @ $I_{\mathrm{max}} \simeq 3{,}5 \cdot 10^{19}\ \mathrm{W/cm^2}$ the foam layer with the <u>lowest areal density available is too high</u>

PIC results

- Support and justify experimental results
- Forsee a good working point for +10μm foam:

$$I \gtrsim 10^{20}\ \mathrm{W/cm^2}$$

Future works

- Longer and/or more intense pulses
- New targets with different foam thickness and density

Grating target

Mylar with regular engraving

Grating and Surface Plasma Waves

Surface plasma waves

Solid foils with periodic surface modulation may allow resonant excitation of

Surface Waves (SW)

Surface fragility

Previous investigations *modest* intensities $I \lesssim 10^{16} \mathrm{W/cm^2}$ (preserve structures)

High contrast + Grating target

- Double Plasma Mirror:
  $I > 10^{19}\ \mathrm{W/cm^2}$ contrast $\sim 10^{12}$
- Engraved MYLAR™ foils

Grating effects at the expected angle

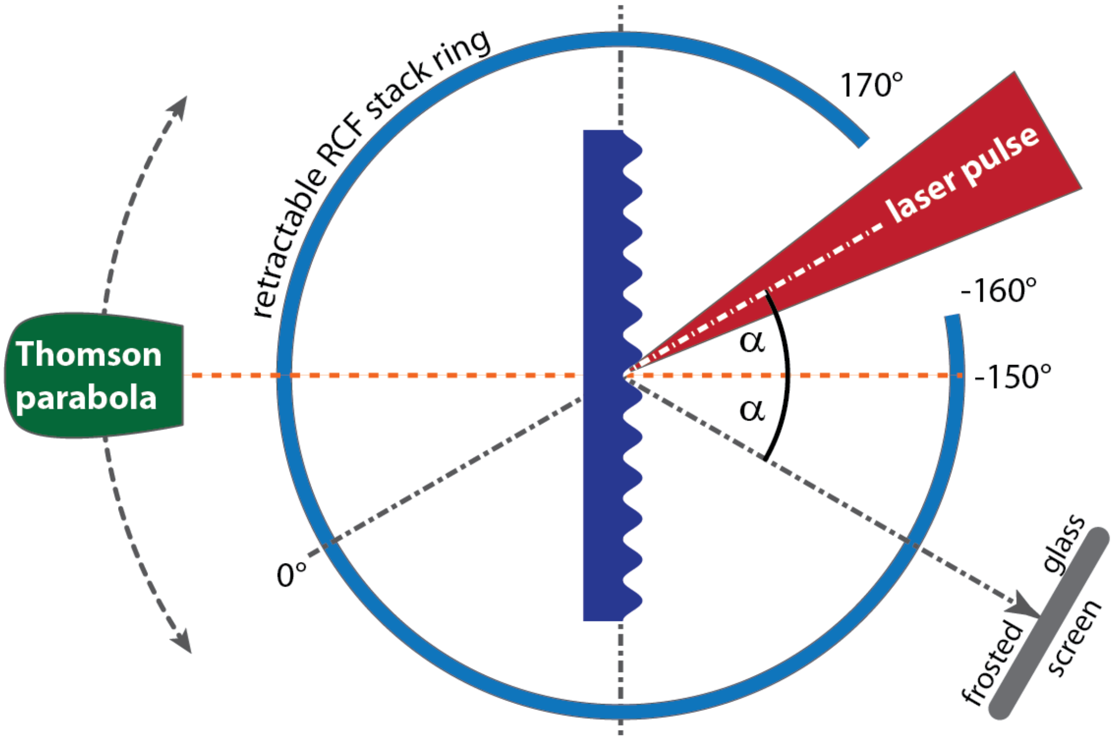
- The **grating** widthstanded the laser prepulse
- Absorption enhancement at **resonant incidence angle**

T. Ceccotti et.al. *accepted on* PRL arxiv.org/abs/1310.2755

Grating setup

- UHI-100 laser pulse
  P-polarized $\tau_p = 25\text{fs}$
  $I_{\max} \simeq 2{,}5 \cdot 10^{19}\,\text{W/cm}^2 \quad w_0 \simeq 3.5\mu\text{m}$
- MYLAR™ foils (0,8 - 20 - 40 µm)
  2λ periodic engraving 500 - 300 nm deep
- Incidence angle θ = [15°: 45°]

Resonant Angle
θ = 30°

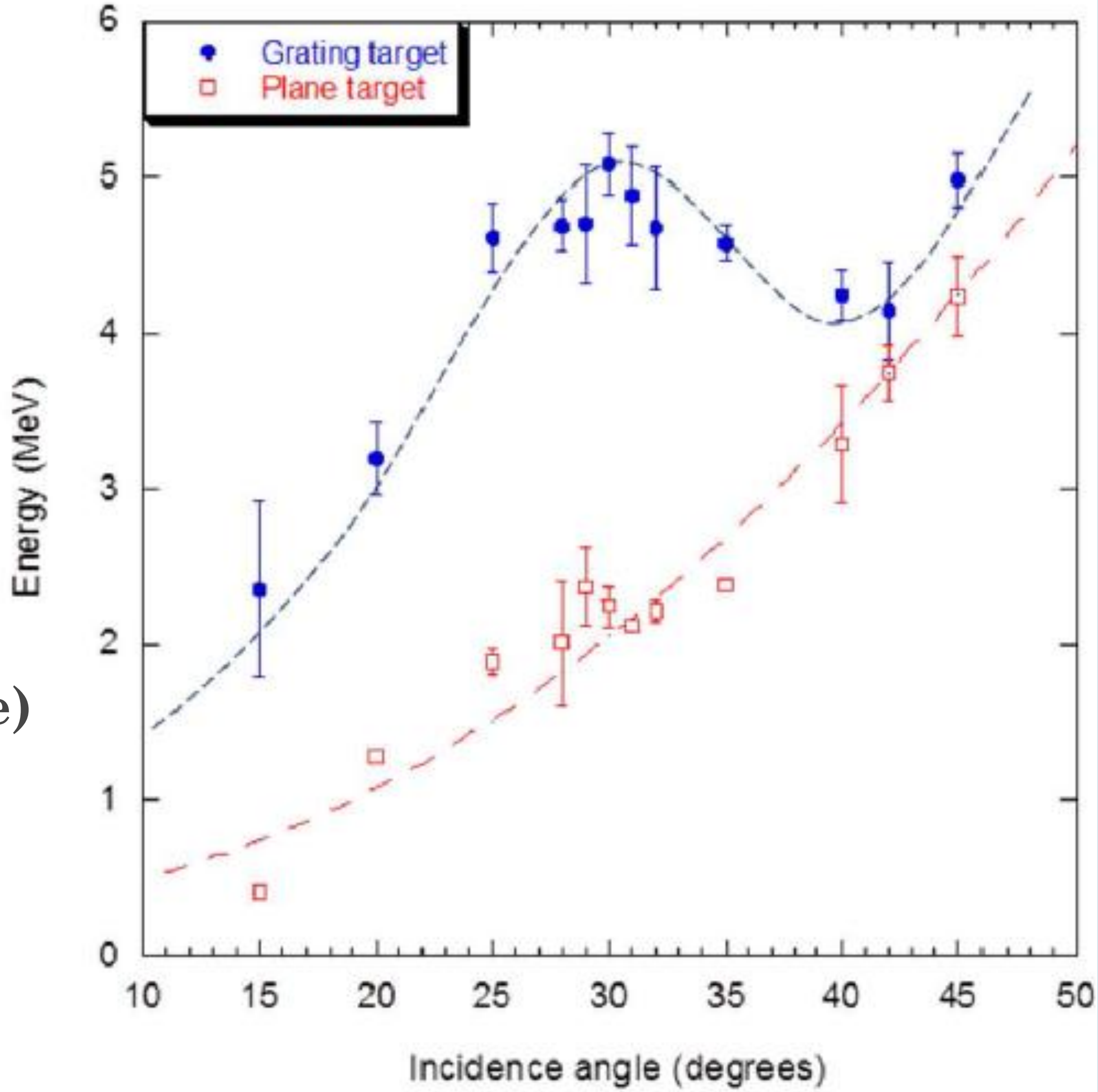


- Thomson parabola on a special rail
- Radiochromic stack around the target for selected shots

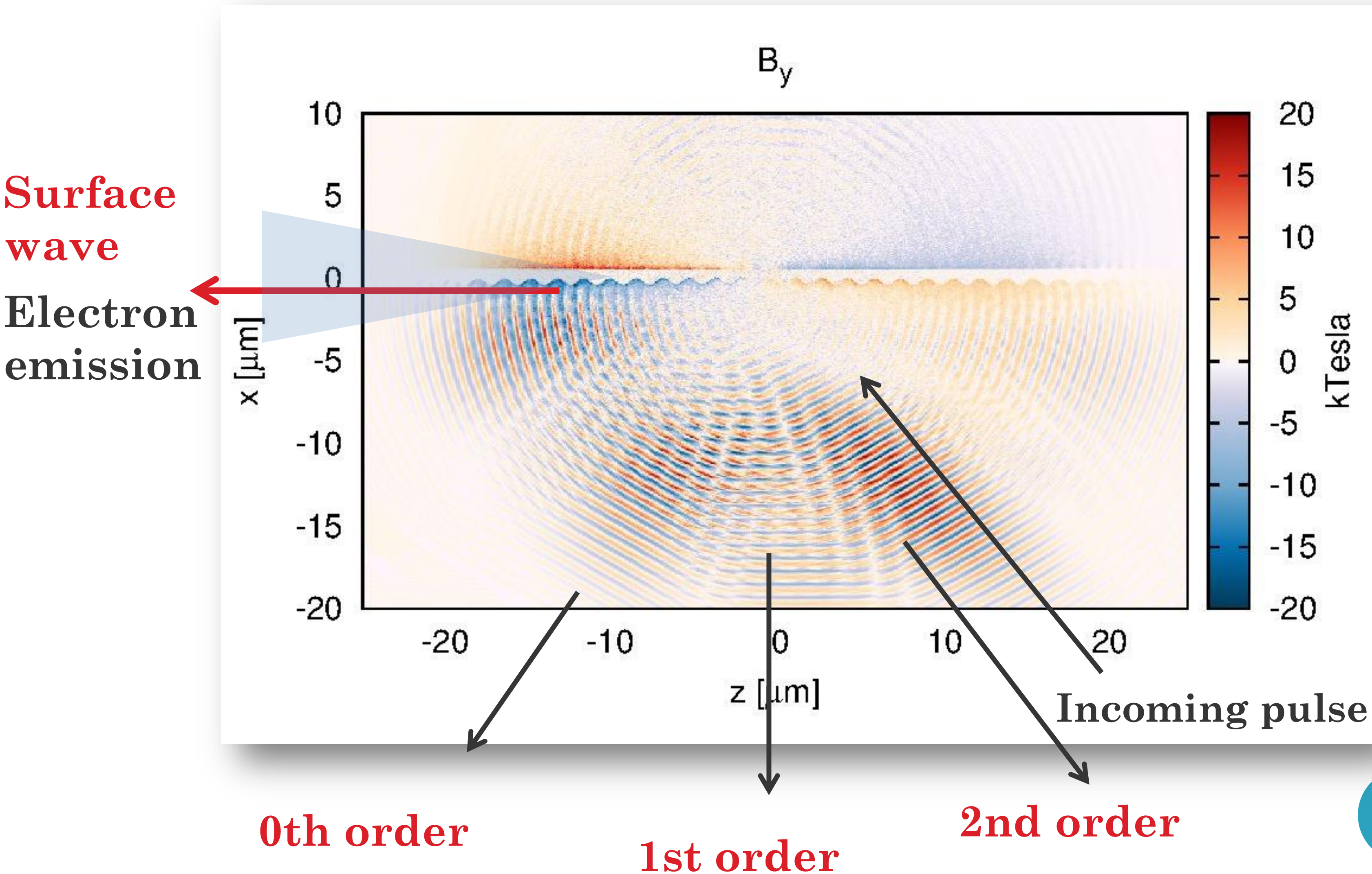
20 MICRON: PROTON MAXIMUM ENERGY

Proton cut-off energy varying incidence angle

- While PT show an expected variation $\mathcal{E}_p \propto 1/\cos\theta$ (dashed)
- GT clearly lead to local maximum at 30° **(resonant angle)**



SURFACE WAVE SIGNATURE



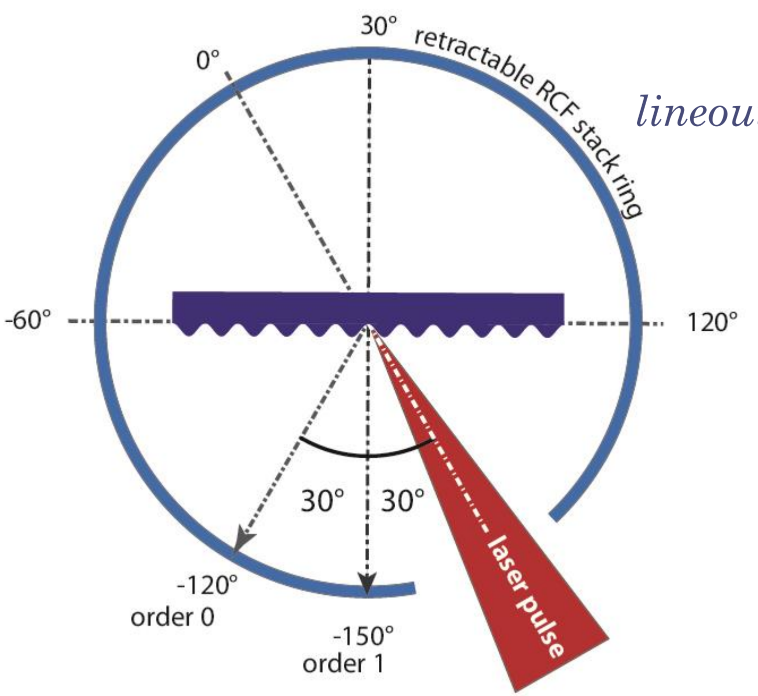
RCF stack: grating, Mylar 20 micron

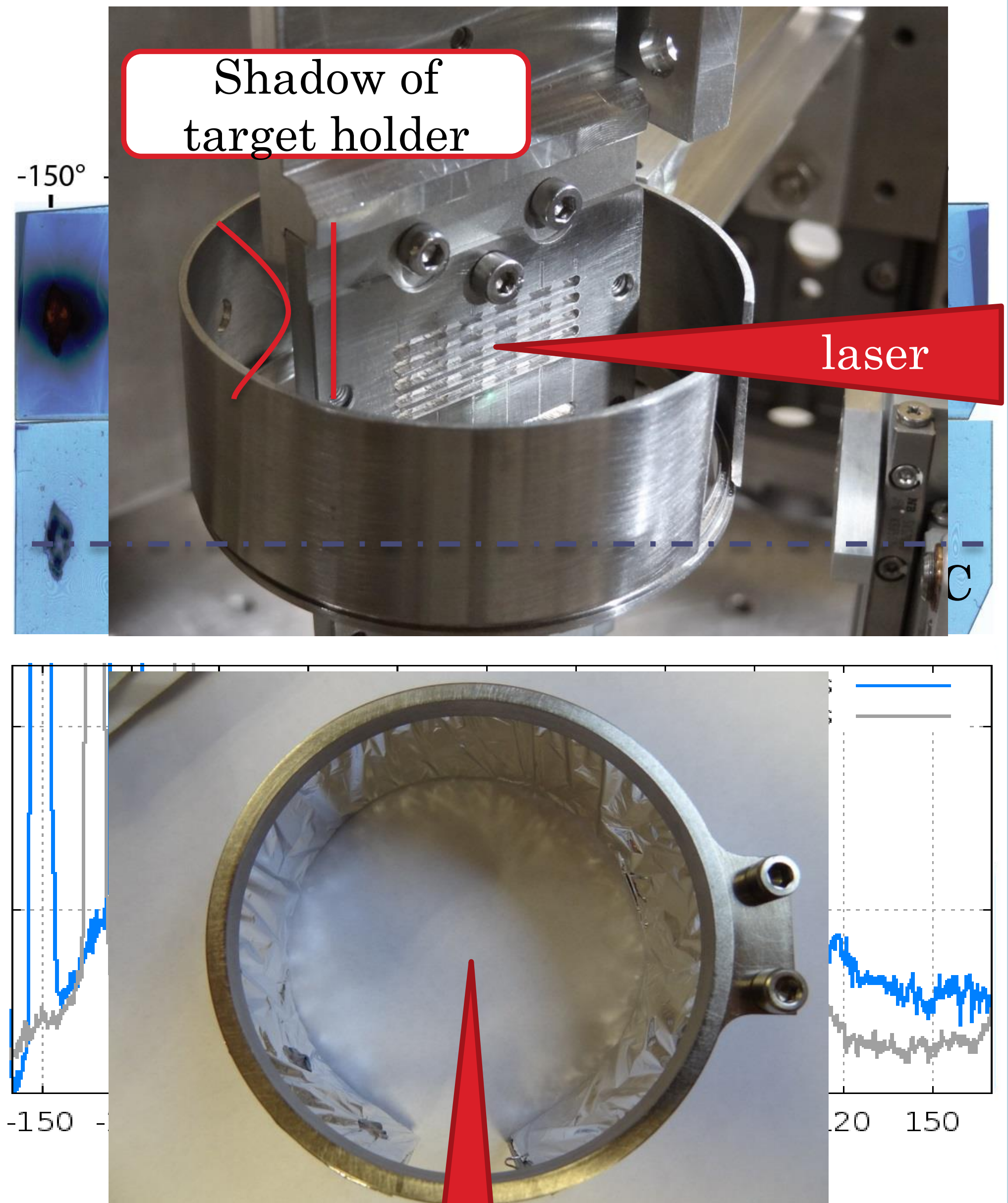
- On selected shot a 3 RCF stack was placed around the target

With High Contrast (HC)

- Two burning spots: double laser reflection: 0 and 1 diffraction orders

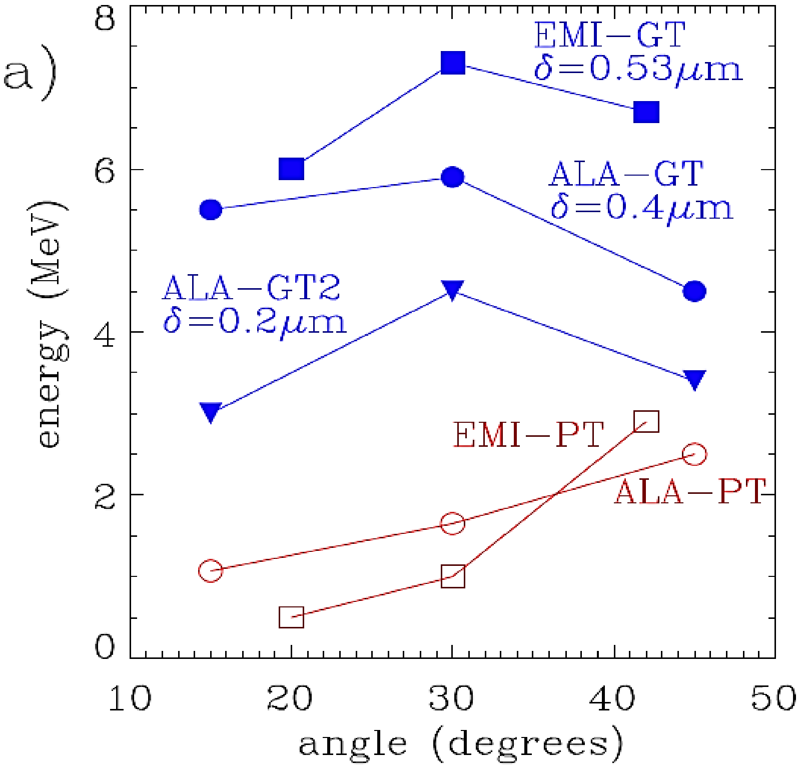
Each case: results of 3 consecutive shots



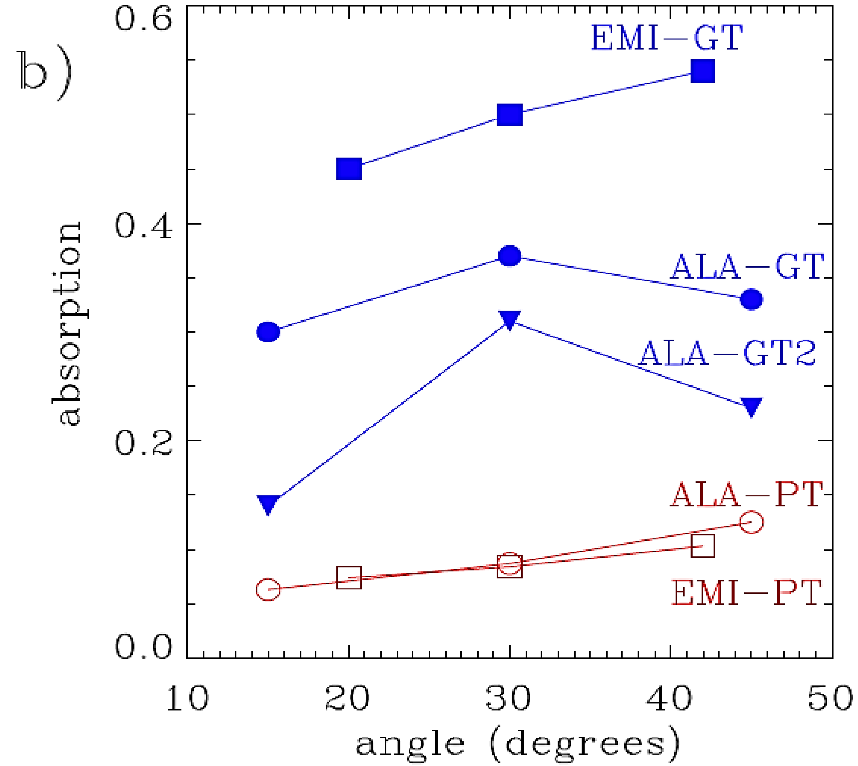


2D PIC: Proton energy & absorption

Proton cut-off energy



Absorbed energy



Two different PIC configuration:

- Thin foil + focussed target
- Plane wave + thick target

Grating vs. Plain target

- increased absorption
- Higher proton energies
- **«resonance» at 30°**

Grating target: conclusions

High intensity high contrast

$I_{\max} \simeq 2{,}5 \cdot 10^{19}\,\mathrm{W/cm^2}$ & high contrast

- Grating integrity for each thickness

Proton acceleration

Clear enhacement at resonant angle
at **relativistic intensity**
Evidence of surface waves excitation

PIC results

Qualitative agreement with exp.

Suggest the presence of a Surface Wave

Future Works

- Test grating with differnent (45º) resonant angle
- Higher intensity laser pulse

Thank you