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Proton and electron acceleration via micro-structured targets

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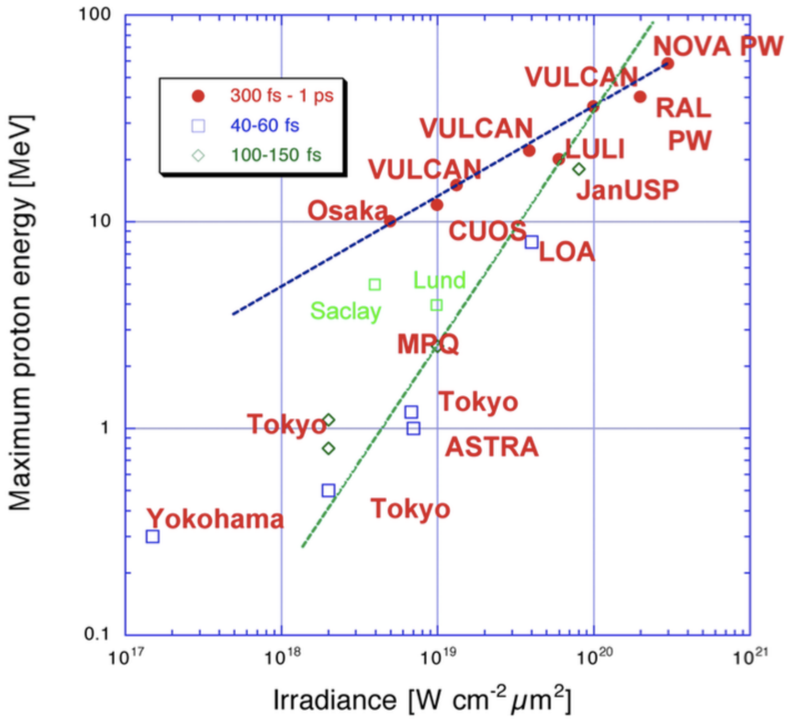
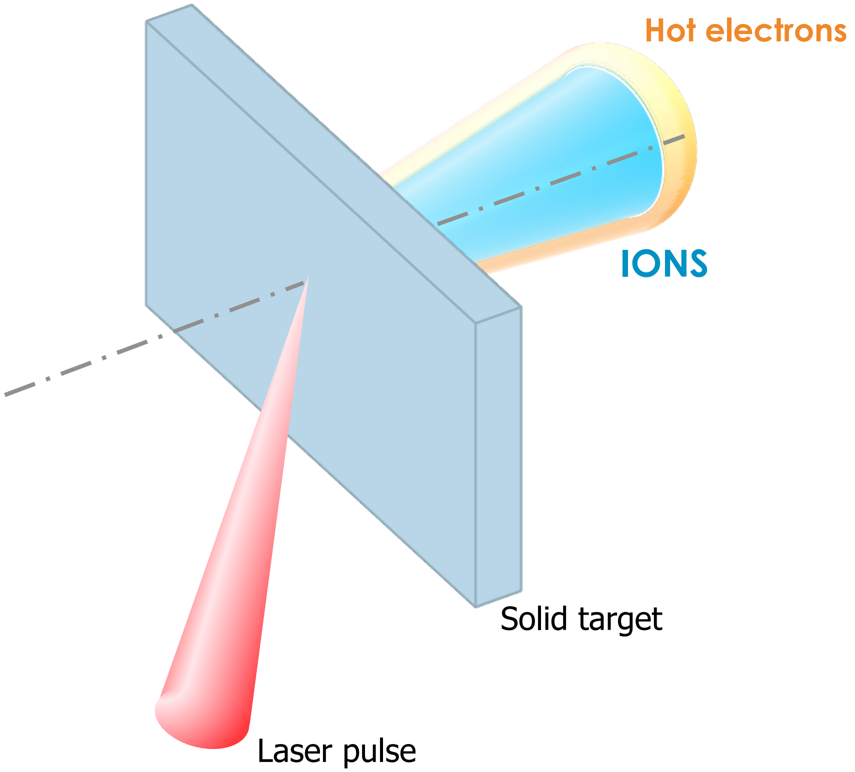
Laser driven ion acceleration from solid targets

Target Normal Sheath Acceleration (**TNSA**)

Open points
- energy spectrum tailoring
- focusability
- higher repetition rate
- **higher cut-off energy**





Hot electrons

IONS

Solid target

Laser pulse

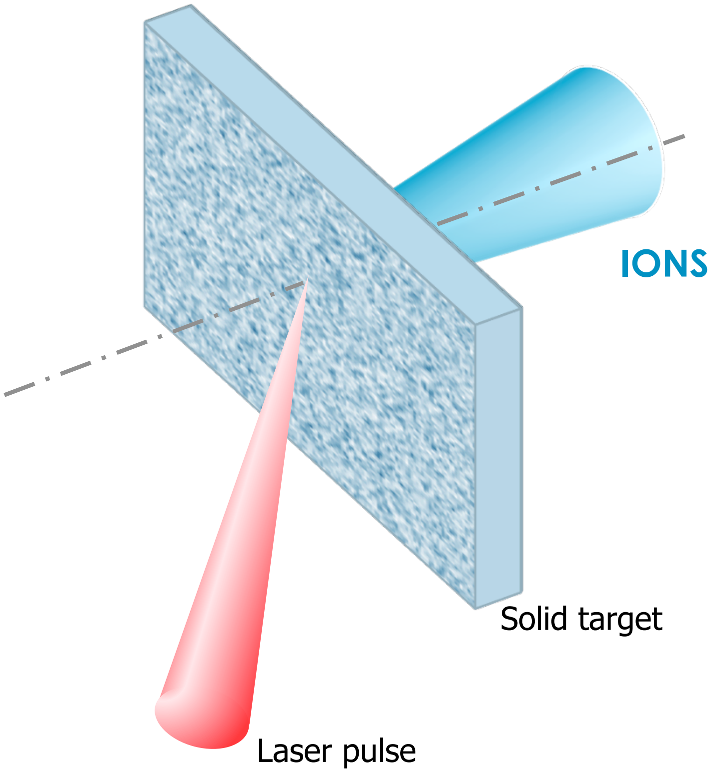
Borghesi et al., Plasma Phys. Control Fusion, **50**, 124040-50 (2008)

>> for TNSA, see Macchi et al., Rev. Mod. Phys. **85**, 751-793 (2013)

How to increase $E_{cut\text{-}off}$?

Ideas/ strategies?

- employing ultra-high power lasers
- varying target thickness & density
- **micro-structured targets**



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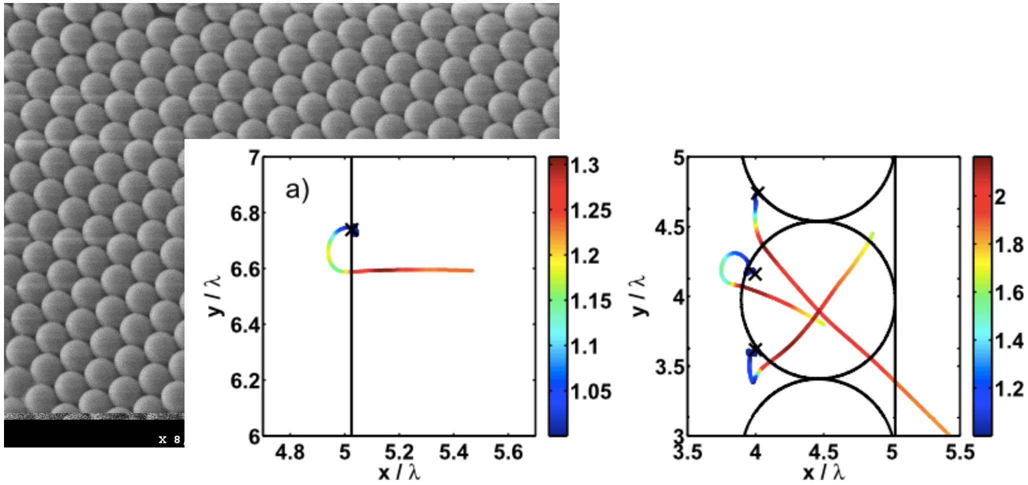
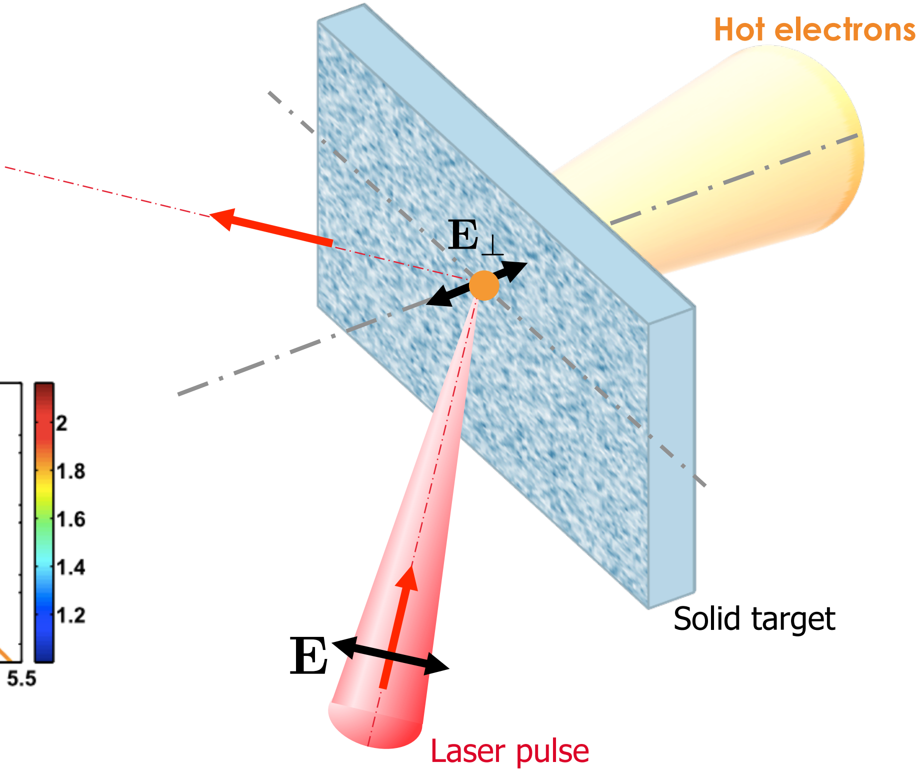


coarse surfaces allow more electrons to be injected in the target



Floquet et al., Journal of Applied Phys., **114**, 3305 (2013)

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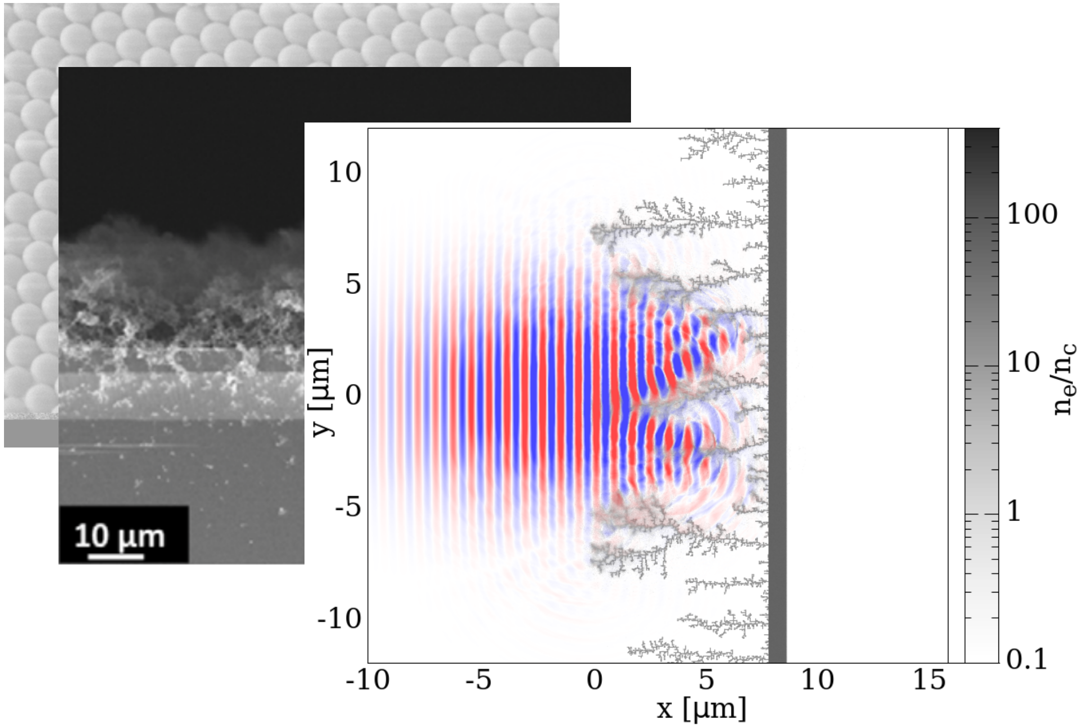
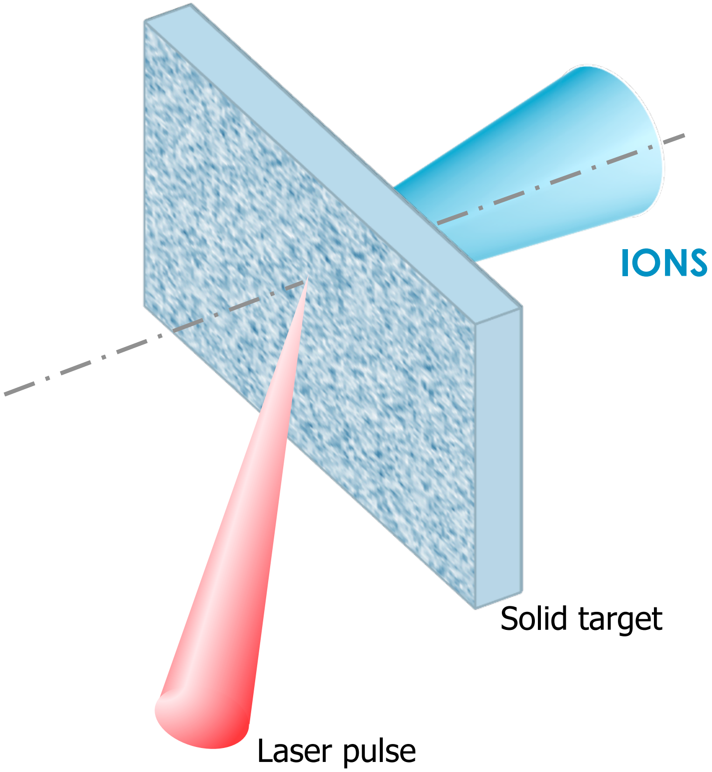


a first layer of near-critical density supports laser propagation and electron extraction



Passoni et al., Plasma Phys. Control. Fusions, **56**, 5001 (2014)

Floquet et al., Journal of Applied Phys., **114**, 3305 (2013)

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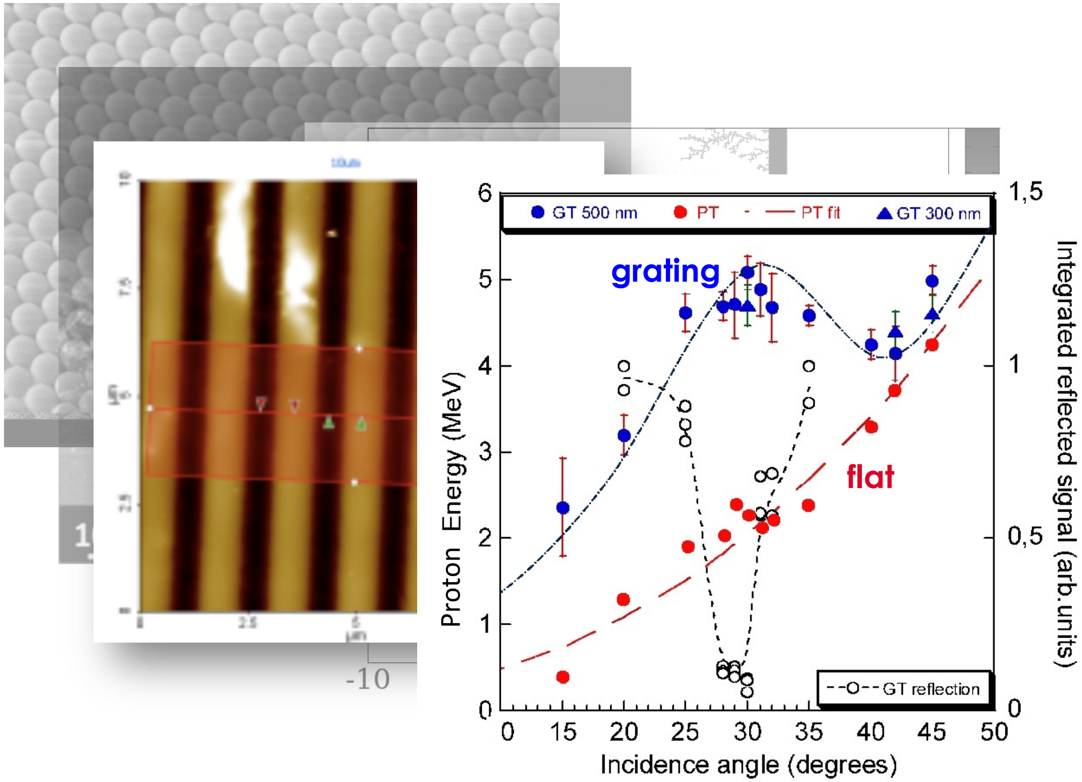
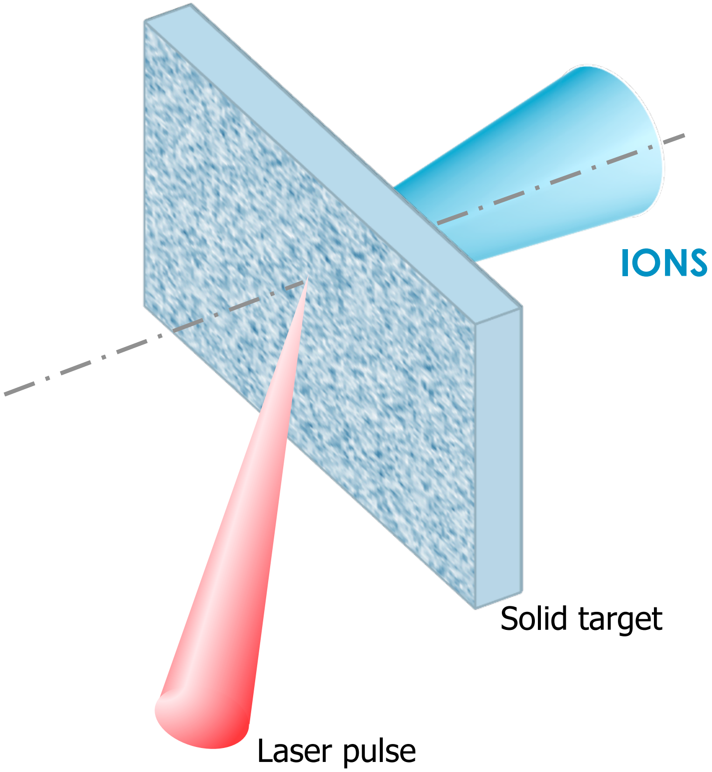




the excitation of normal modes of the target plasma results in increased absorption

Ceccotti et al., Phys. Rev. Lett., 111, 5001 (2013)

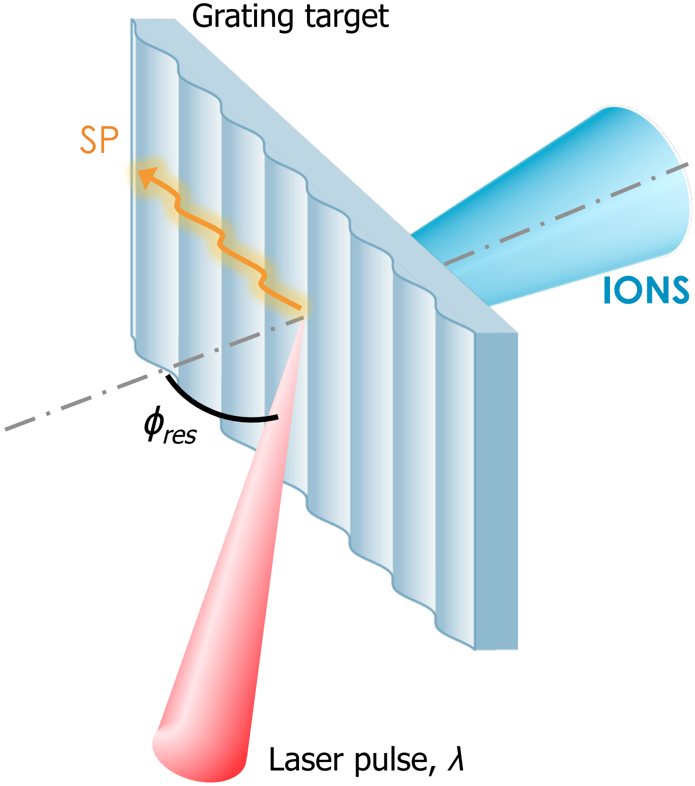
Passoni et al., Plasma Phys. Control. Fusions, **56**, 5001 (2014)

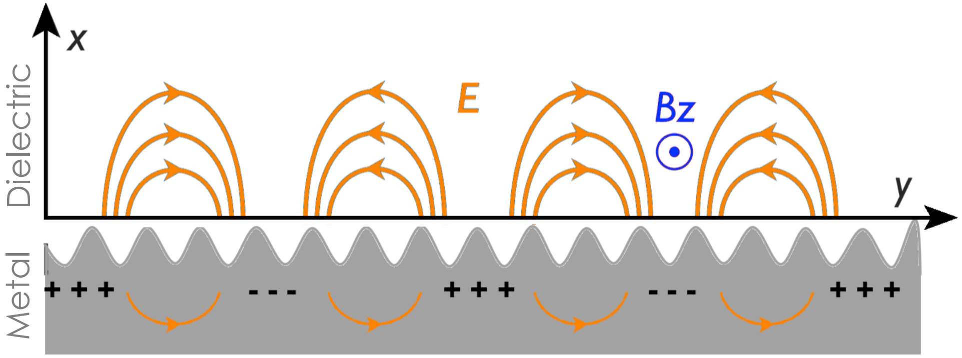
Floquet et al., Journal of Applied Phys., **114**, 3305 (2013)

Surface Plasmon excitation on grating targets

SP: electron oscillation resonant modes at the solid-vacuum interface

Phase matching in order to obtain the *resonant coupling* between laser & SP requires a *periodic surface*





$$\mathbf{k}_{\|}^{\text{laser}} = \mathbf{k}_{\mathbf{SW}}(\omega) \pm \mathbf{nq}$$

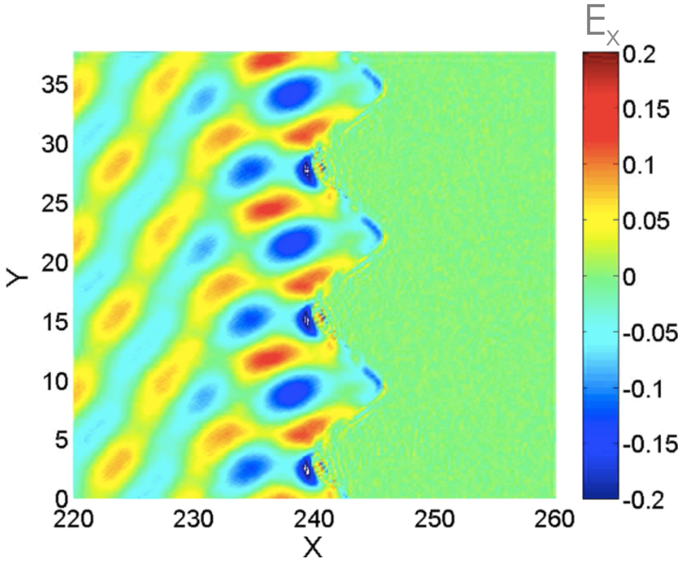
$$\sin\left(\phi_{res}\right) = \sqrt{\frac{\omega_p^2 - \omega^2}{\omega_p^2 - 2\omega^2}} \pm n\frac{\lambda}{d}$$

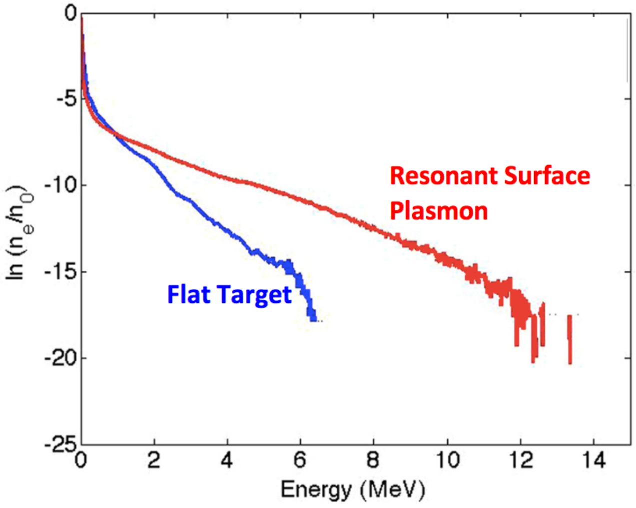
resonance condition

Pitarke et al., Reports on Progress in Physics **70**, (1):1 (2007)

How SPs affect particle acceleration

transverse SP field enhances hot electron production (both energy and number) and drives high energy protons





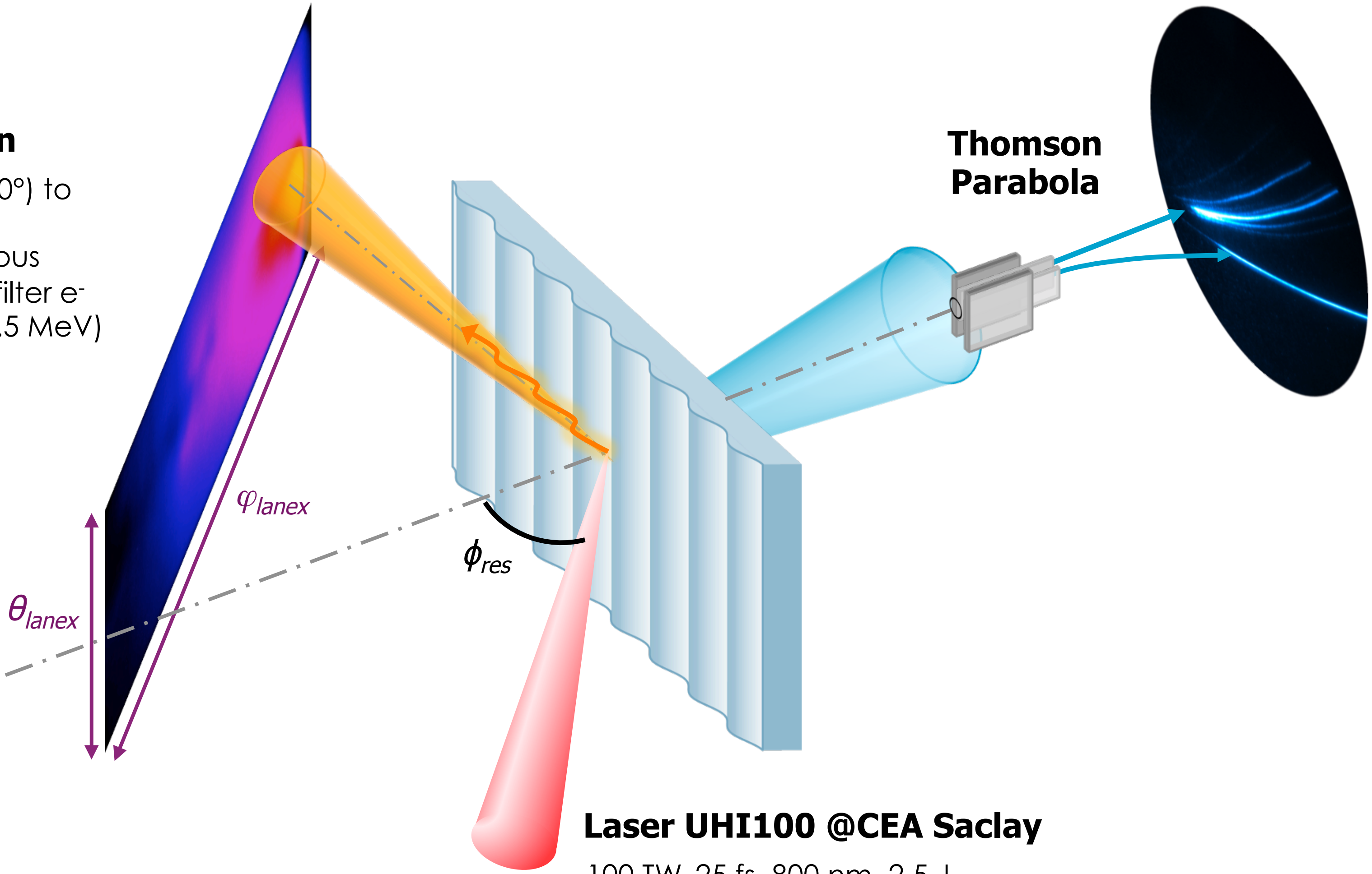
parallel SP field accelerates **electrons** along the target surface;

transverse field component imposes an emission angle ≠ 0° (from tangent);

test electron trajectory

Fedeli et al., arXiv:1508.02328
Sgattoni et al., Plasma Phys. Control. Fusion, accepted (2015)
Bigongiari et al., ion: Phys. Plasmas **18**, 102701 (2011)
Bigongiari et al., Phys. of Plasmas **20**, 2701 (2013)

Looking for electron acceleration by relativistic SPs



Lanex screen

from tangent (0°) to normal (90°)
Al filters of various thicknesses to filter e^- energy ($E_{e^-} < 1.5$ MeV)

Thomson Parabola

Laser UHI100 @CEA Saclay

100 TW, 25 fs, 800 nm, 2.5 J
$I_L = 5\text{x}10^{19}$ W/cm^2 (f/3.75 & Deformable Mirror)
contrast 10^{12} (Double Plasma Mirror)

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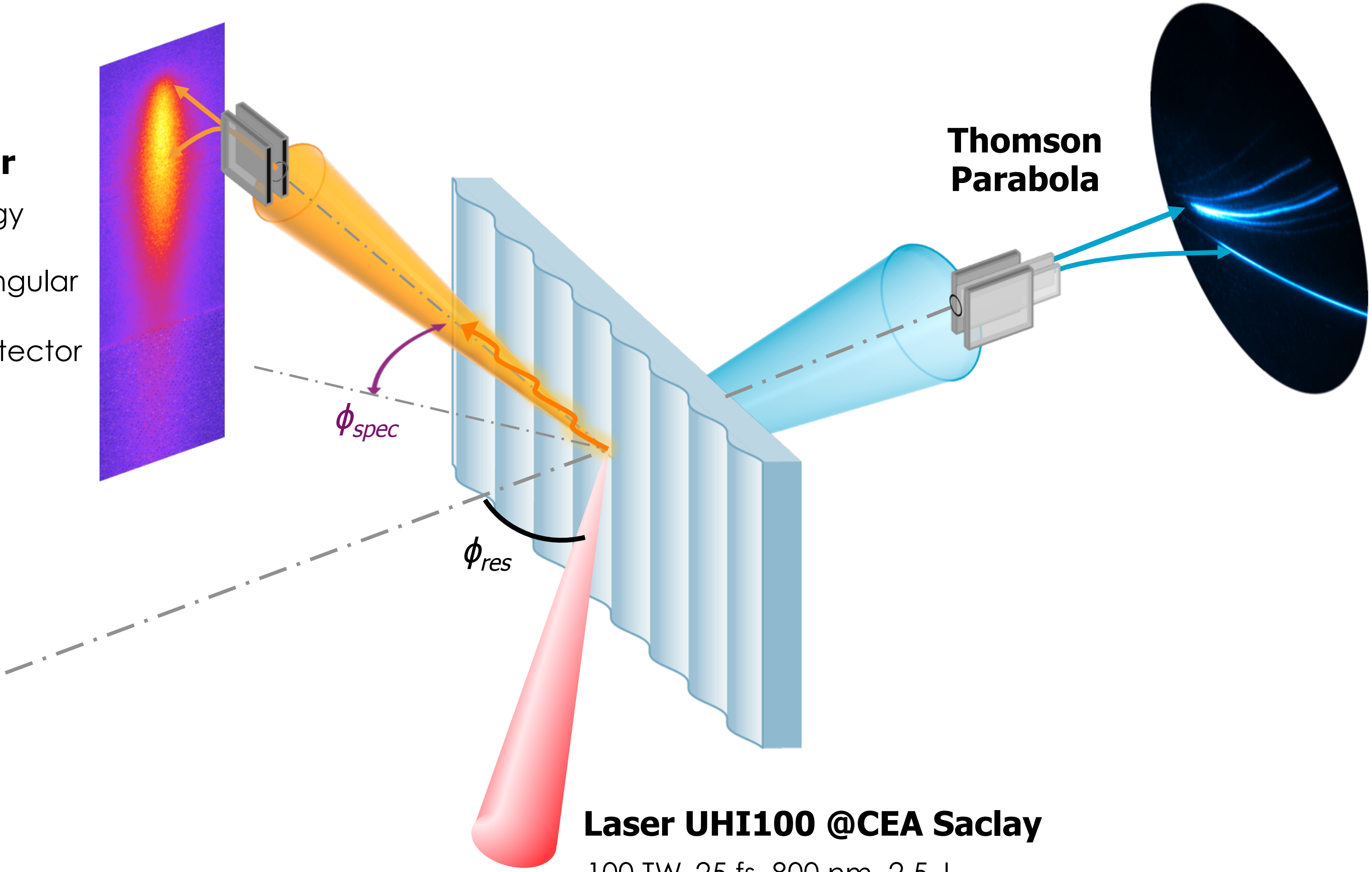

Electron spectrometer

2-30 MeV energy range
covering 60° angular range (ϕ_{spec})
12bit CMOS detector

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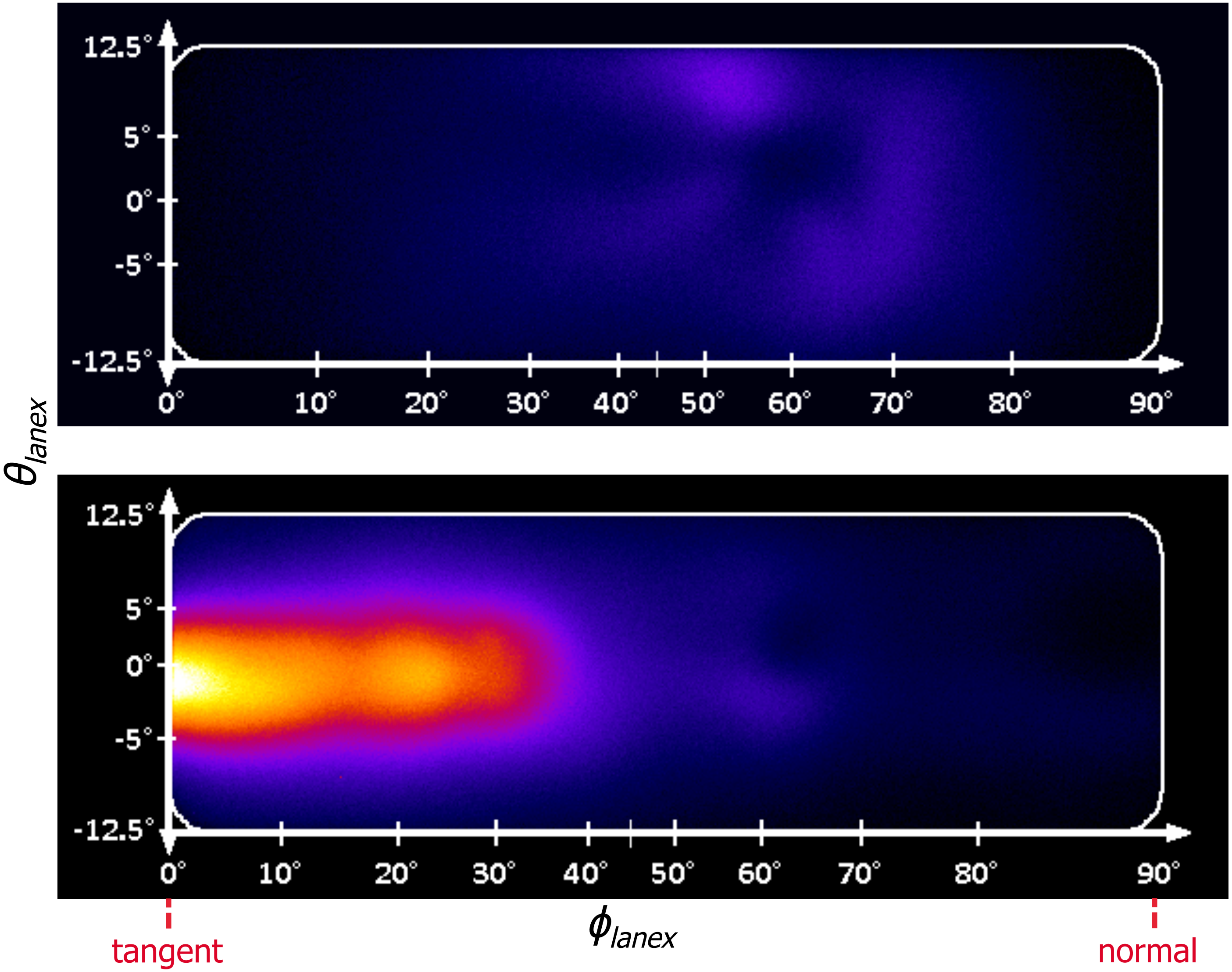
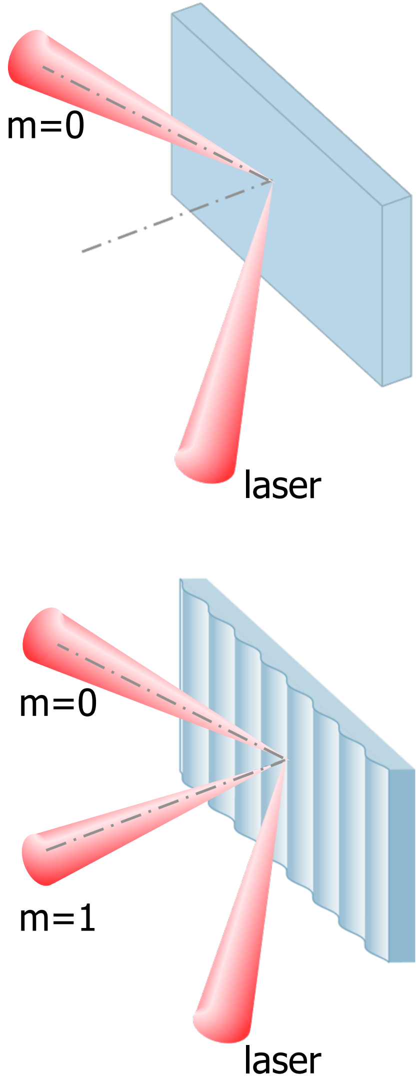
Spatial distribution

Flat vs Grating @ resonance (30° inc.)





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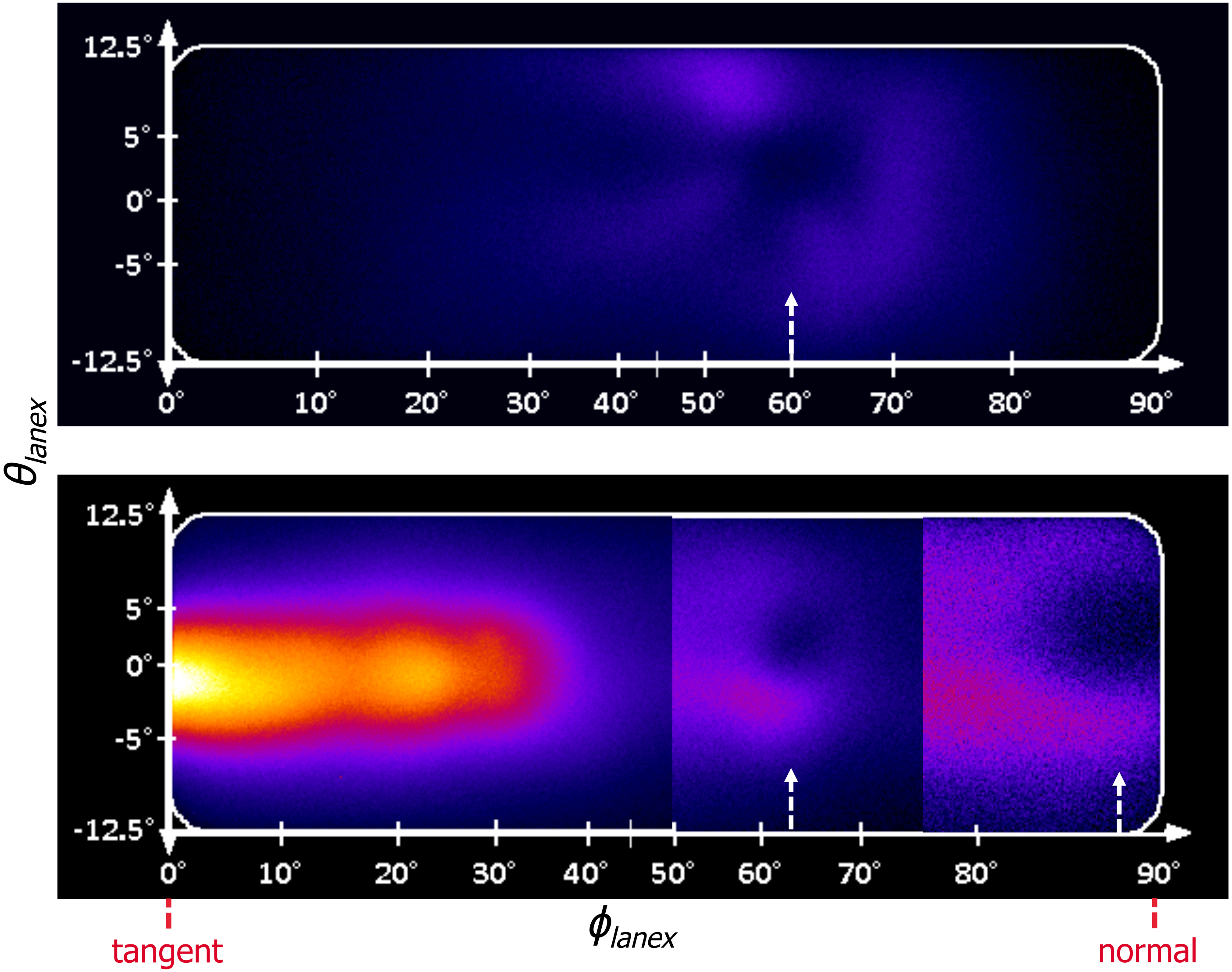
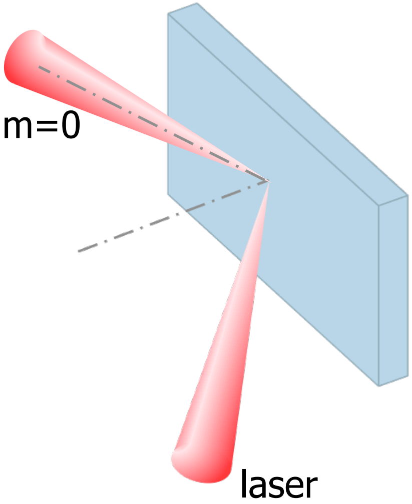
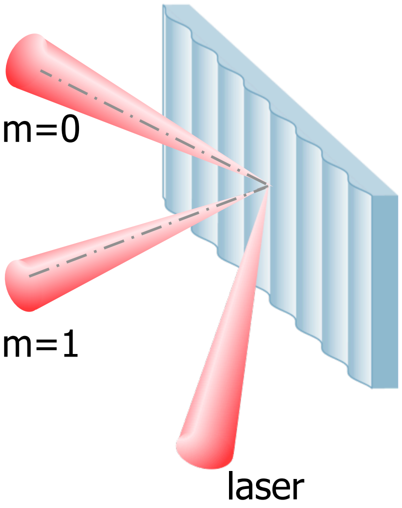
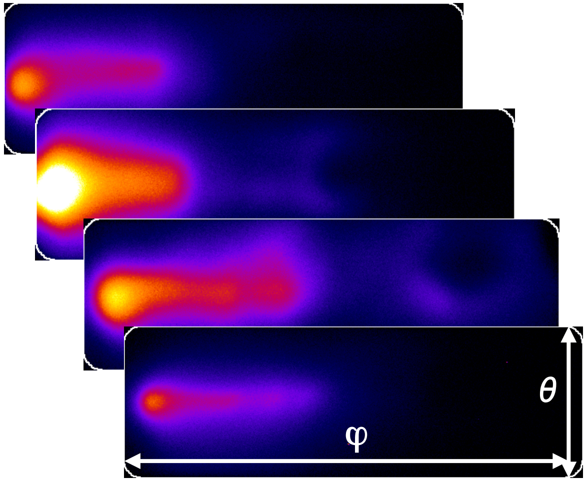




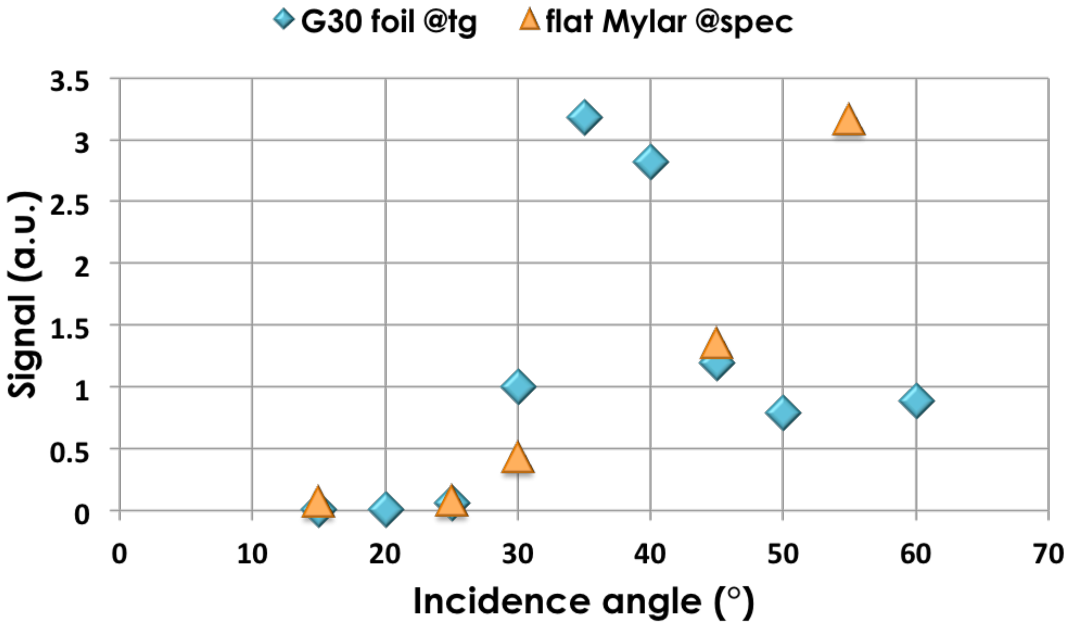


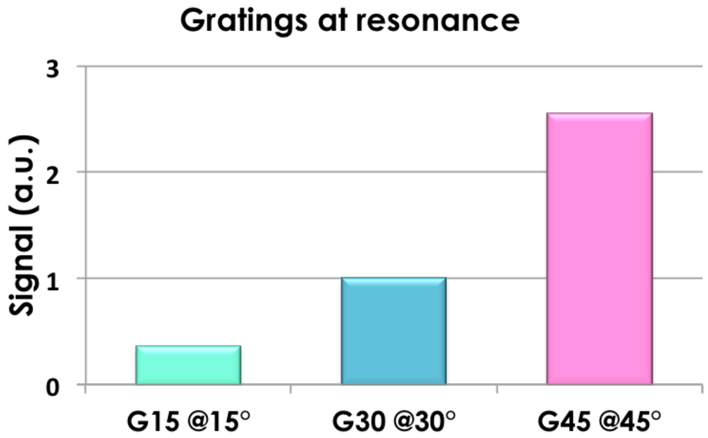
Flat vs Grating targets

Gratings at resonance	φ (± 0.5°)	*θ* (± 1°)	Divergence (Full Angle)	Charge in the bunch (pC)★
G30	2.0°	-2.1°	8.5°	**60**
SG30	2.5°	-1.4°	10°	70
G15	4.4°	-2.0°	8.4°	20
G45	4.2°	0.0°	7.5°	**120**
Flat @55° inc	35°	-	>34°*	**70****



★ electrons with energy > 1.5 MeV
*signal over whole lanex
** signal of the brightest bunch (10° divergence FA)





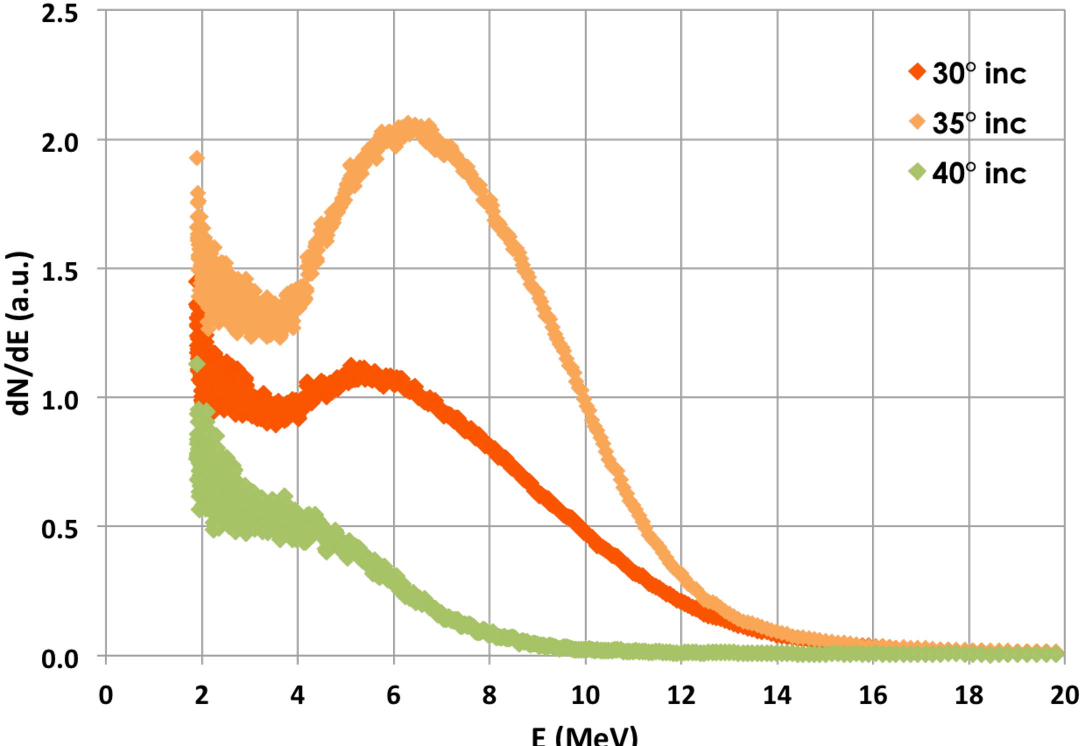
Electron spectra

Experiment & Simulations

recorded with ϕ_{spec}= 2° from tangent

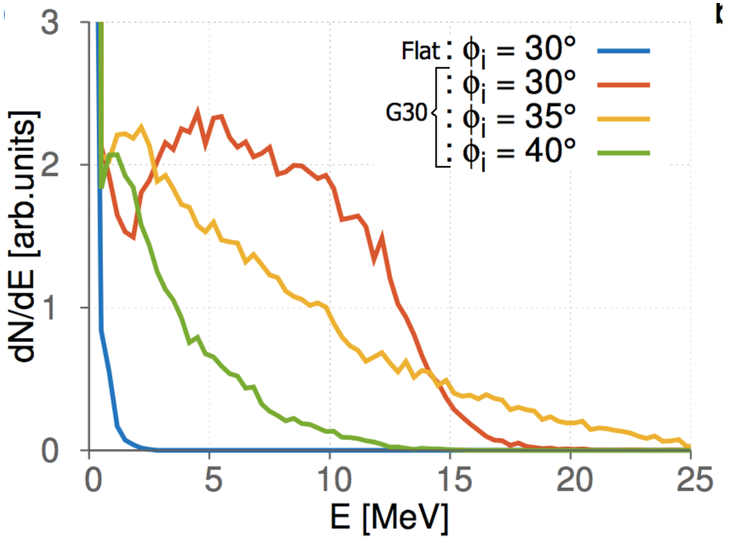
No spectrum above the noise level **with FLAT target**

G30 at resonance:
- stronger signal
- higher cut-off energy (>15 MeV)
- broad peak at 5-8 MeV and dip at 3-4 MeV



3D PIC simulations performed with PICCANTE

Energy-emission angle correlation revealed by 3D simulations



http://aladyn.github.io/piccante/
http://www.prace-ri.eu/IMG/pdf/WP209.pdf

What’s next?

High field plasmonic is accessible thanks to ultra-high contrast laser systems; Surface plasmons do improve laser-target coupling and result in enhanced proton and electron acceleration

- Compare experimental results with PIC simulations (PhD in joint supervision – UniPi)
- Further characterisation of the electron bunch:
  - Scaling Laws (laser intensity, energy or duration, focal spot size)
  - Emittance
  - Duration
- Applications (UED…)

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Istituto Nazionale di Ottica - CNR - PISA - Italy - INTENSE LASER IRRADIATION LABORATORY

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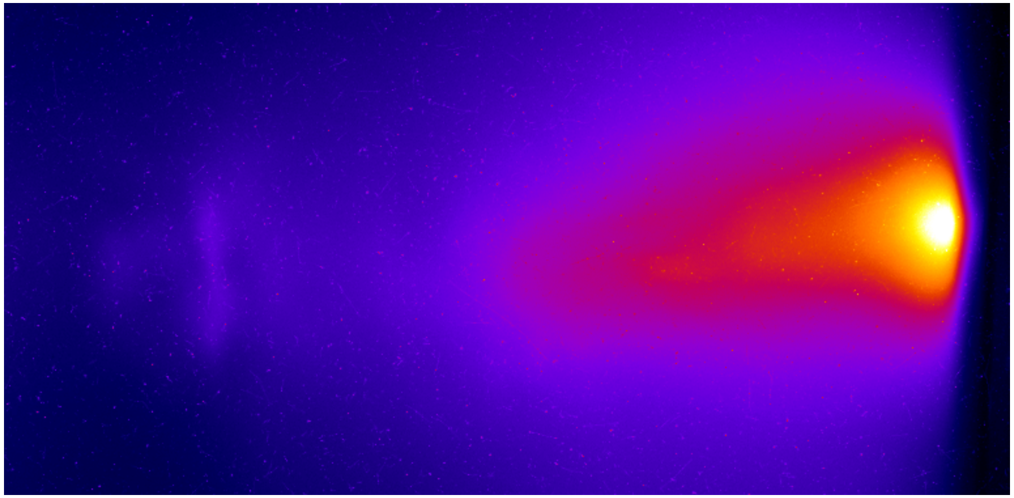


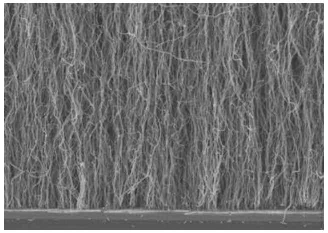
First observations at **CoReLS** (Gwangju, South Korea) – July 2015

GIST
광주과학기술원
Gwangju Institute of Science and Technology

PW laser facility
Grating survive to ultra-high laser intensity (I = 4×10^{20} W/cm^2)

Additional targets for protons enhancement

First try with Carbon Nanotubes
($\varnothing_{ext}$ 40 nm, $\varnothing_{int}$ 20nm, spacing 300nm, length 15÷90 um)
substrates Si3N4 1um, Si 20um

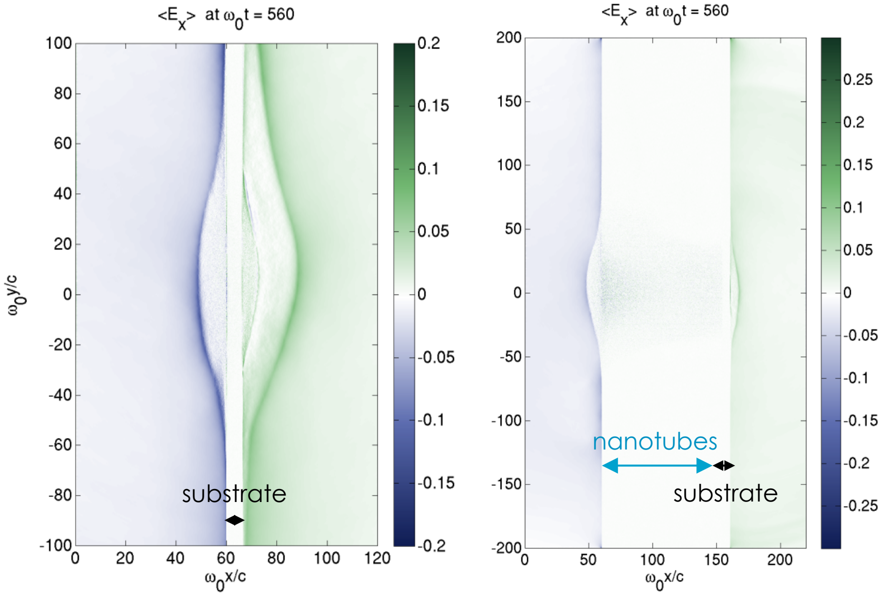


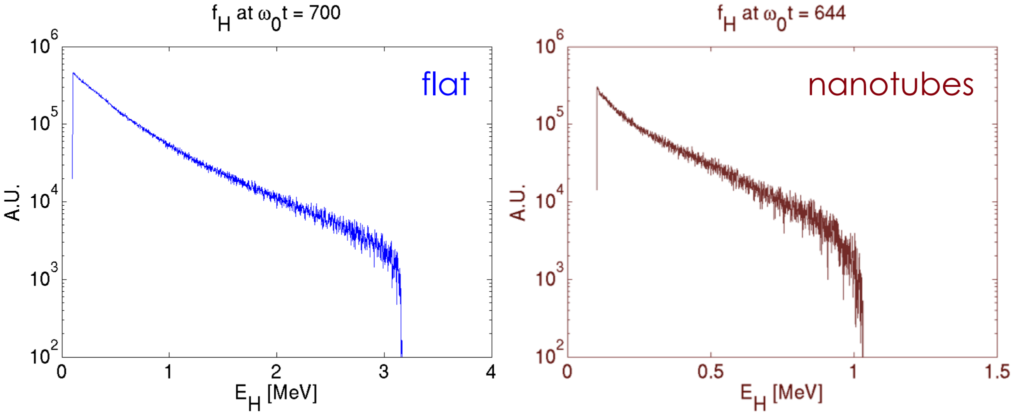
Main results:

nanotubes do increase target absorption

however, few fast electrons get to the rear surface, resulting in a weak accelerating field

protons are **NOT** accelerated efficiently





proton spectra & accelerating electric field from 2D PIC simulations

Future work: next try with shorter (1um), less dense (1um spacing) nanotubes – Feb. 2016

Thank you
for your attention