POLITECNICO
MILANO 1863

Numerical simulations of nanostructured plasmas: enhanced laser-driven harmonic sources and near-critical plasmas

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Belfast, 27/06/2017

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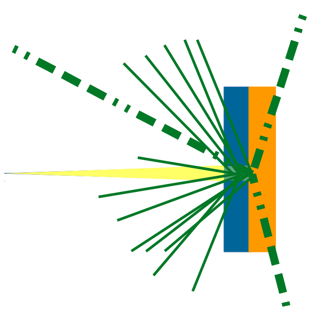
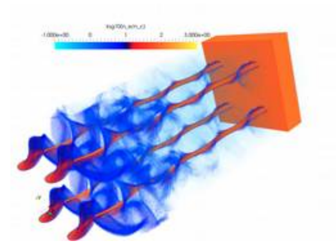
Matteo Passoni
Associate professor

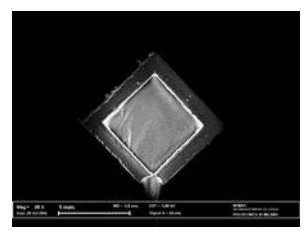
ERC-2014-CoG No.647554
ENSURE



Materials science applications of laser-driven sources



Laboratory astrophysics & nanostructured plasmas



Advanced targetry

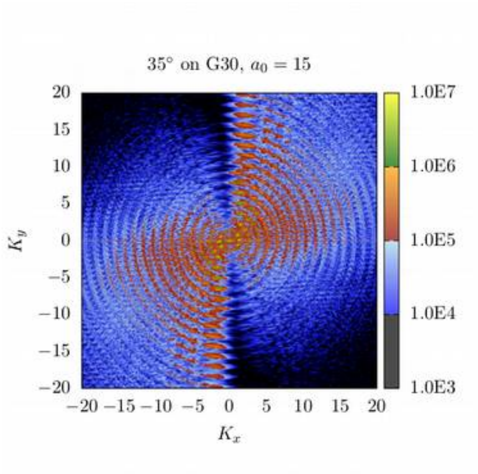
Ongoing collaborations with:

HZDR
OSAKA UNIVERSITY
SourceLAB
ERC-PoC: **INTER**
Queen's University Belfast

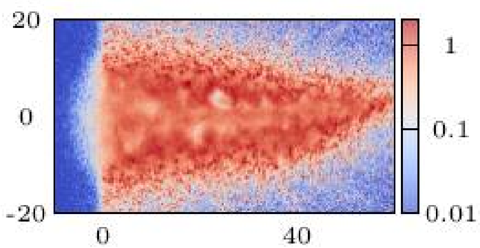
Numerical simulations of nanostructured plasmas: enhanced laser-driven harmonic sources and near-critical plasmas

Ultra-intense, ultra-high contrast fs lasers allow an irradiated nanostructured solid to retain its structure long enough to influence the interaction with the pulse

Outline
Two different topics which involve "nanostructured" plasmas

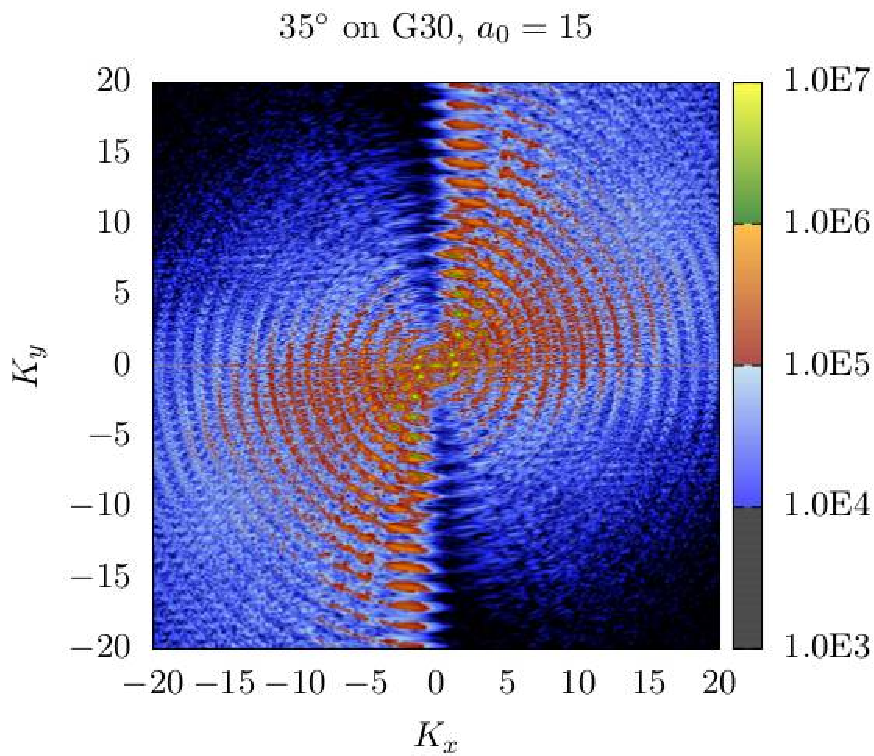


Resonant enhancement of HHG with irradiated grating targets



Laser interaction with nanostructured near-critical plasmas

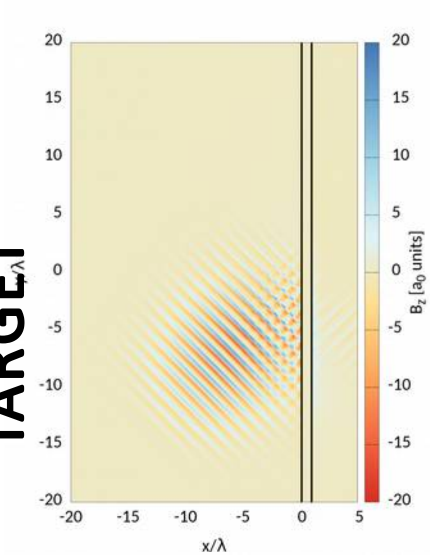
Resonant enhancement of HHG with grating targets



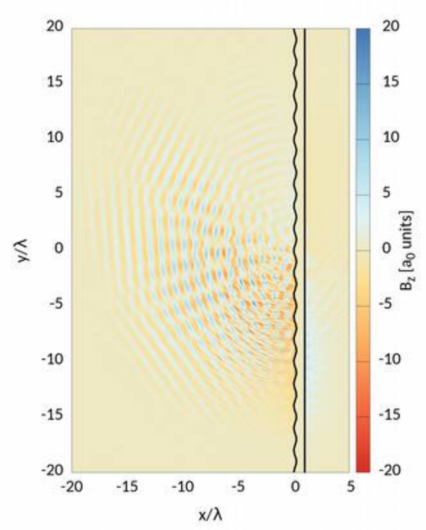
L.Fedeli, A.Sgattoni, G.Cantono & A.Macchi
Appl. Phys. Lett. 110, 051103 (2017)

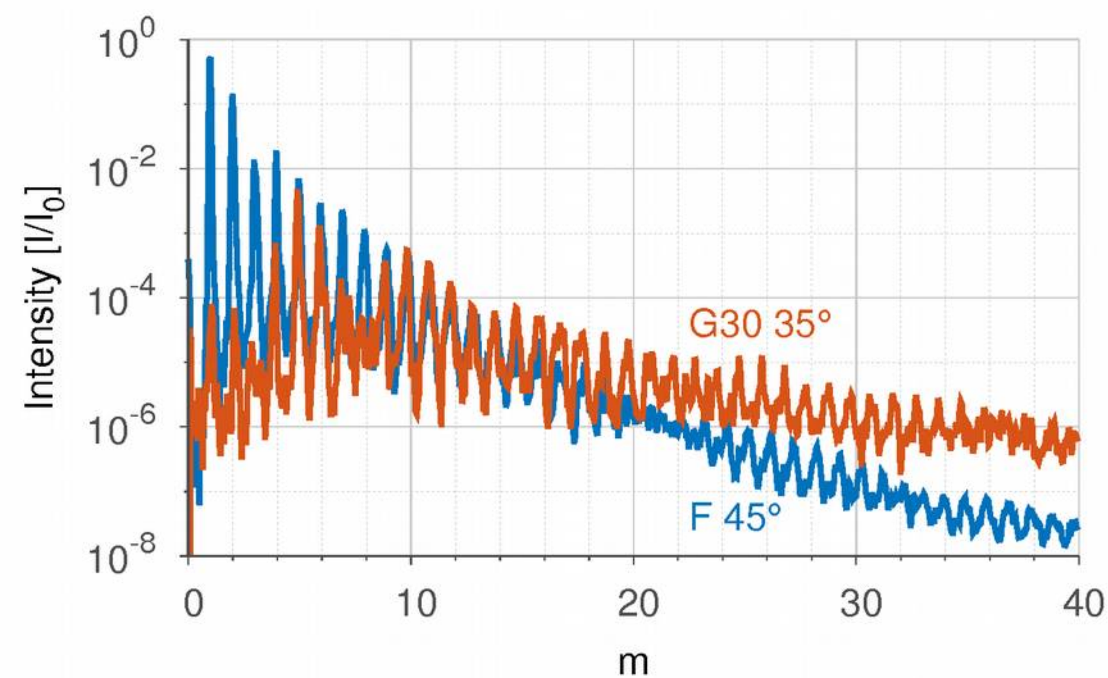
Grating targets irradiated at surface plasmon resonance angle provide Enhanced HHG with respect to simple flat targets

FLAT TARGET



GRATING @ RESONANCE

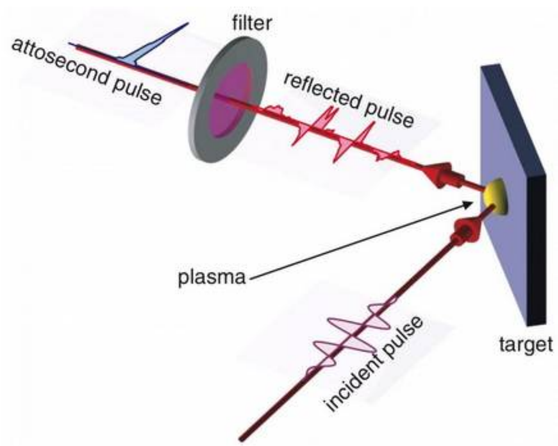


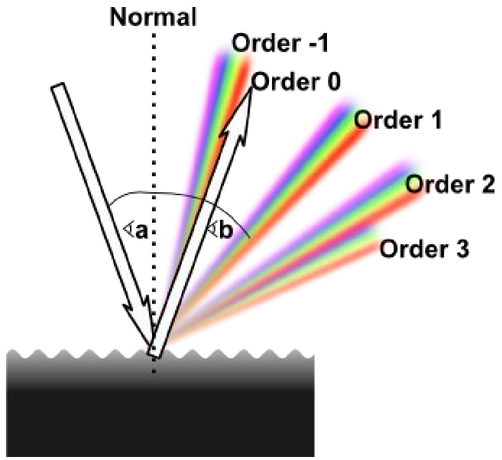


CINECA

piccante
Open Source PIC Code

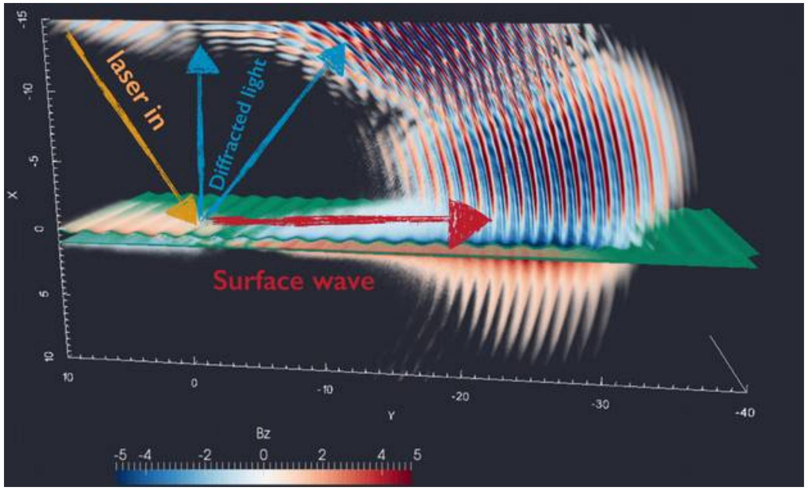
Three ingredients





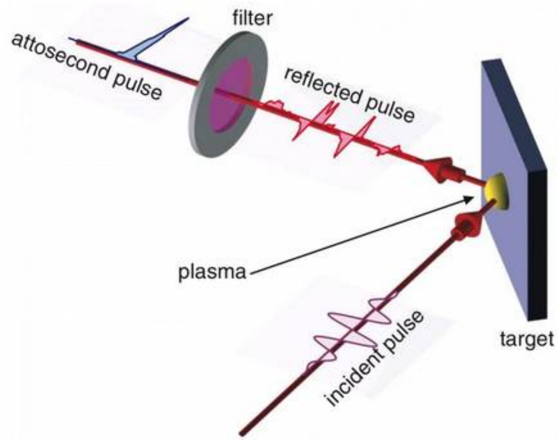
HHG with irradiated solid targets

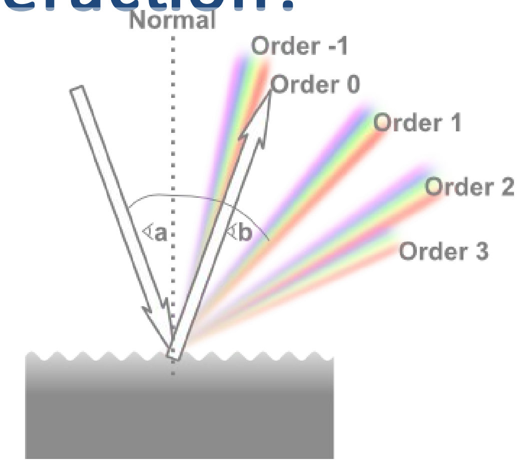
HHG with gratings



Grating targets irradiated
At resonance angle for surface plasmon excitation

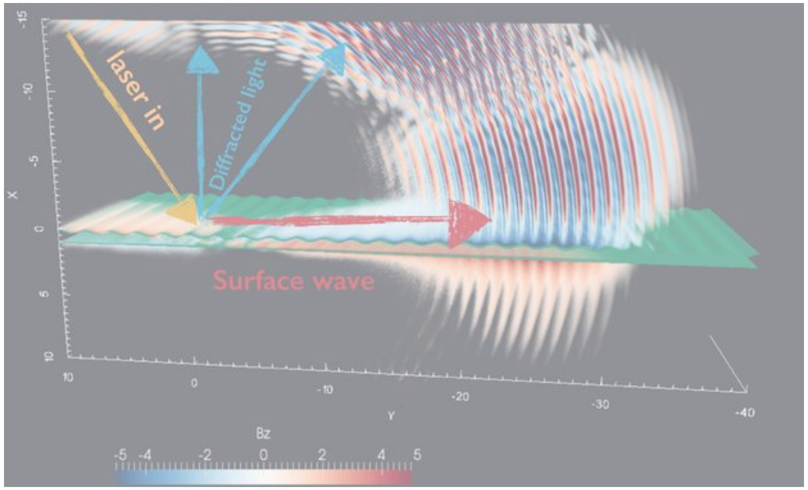
HHG with ultra-intense laser-solid interaction?





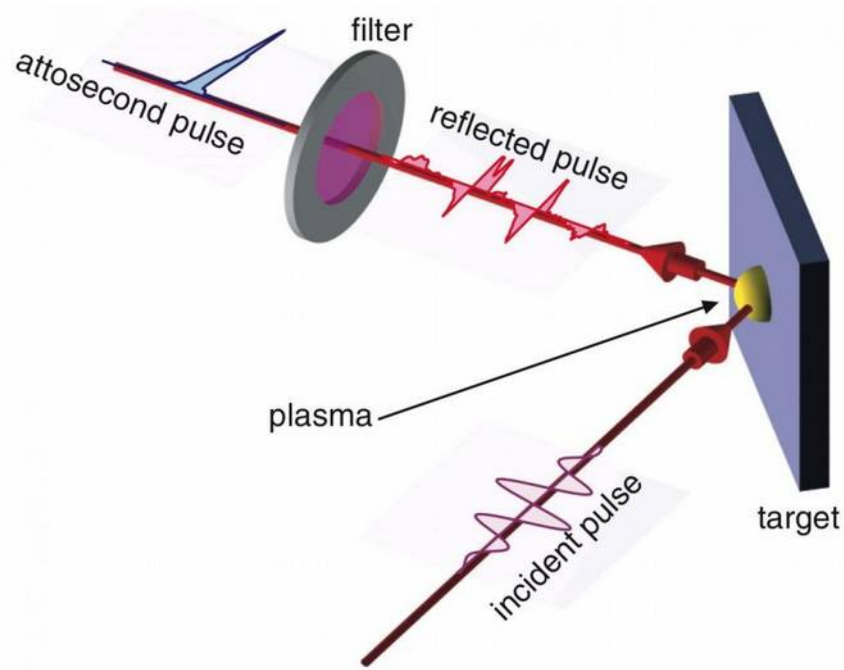
HHG with irradiated solid targets

HHG with gratings



Grating targets irradiated
At resonance angle for surface plasmon excitation

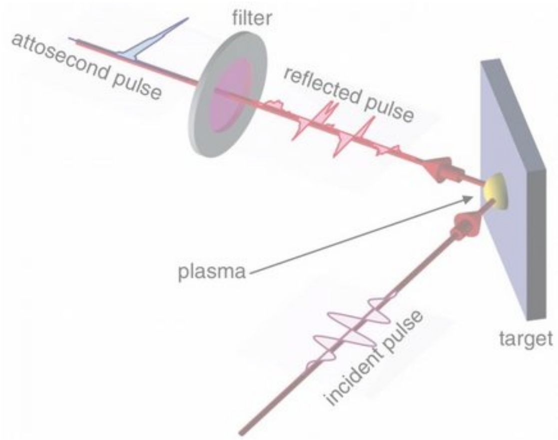
Framework:
HHG with ultra-intense laser-solid interaction

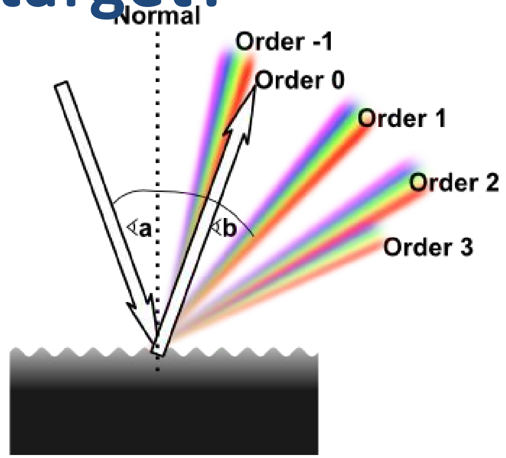


No a priori limits for the maximum **intensity** (relativistic oscillating mirror)

Teubner et al. 2009. RevModPhys,81
Vincenti et al. 2012. PRL, 108

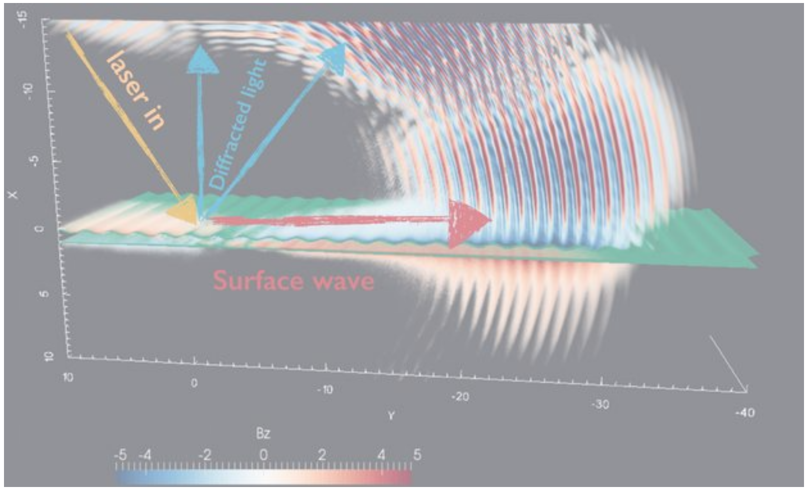
And why should I use a grating as a target?





HHG with irradiated solid targets

HHG with gratings

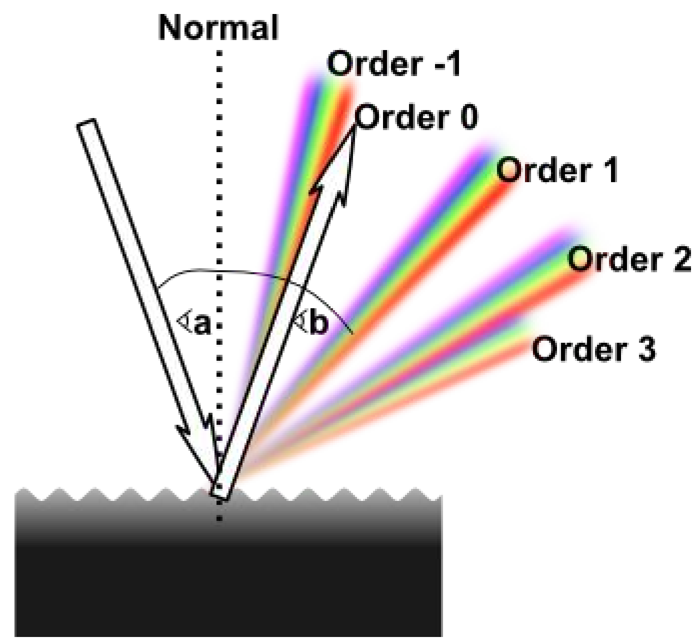


Grating targets irradiated
At resonance angle for surface plasmon excitation

And why should I use a grating as a target?

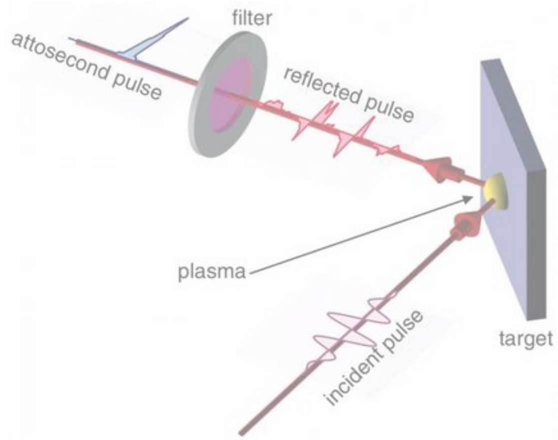
If we use a grating
We can separate the
Harmonics →
 quasi-monochromatic
source

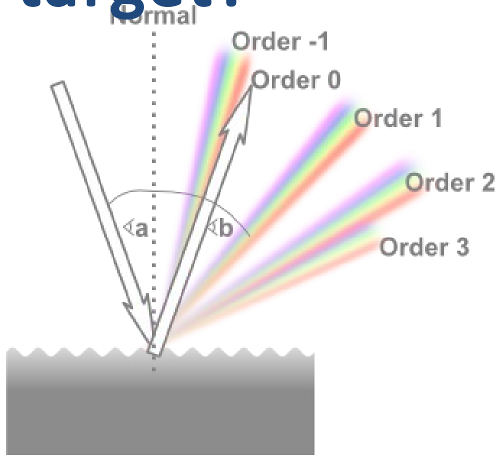
$$\frac{n\lambda}{m\,d}=\sin(\theta_i)+\sin(\theta_{mn})$$



X. Lavocat-Dubuis & J.P. Matte PoP 17 2010

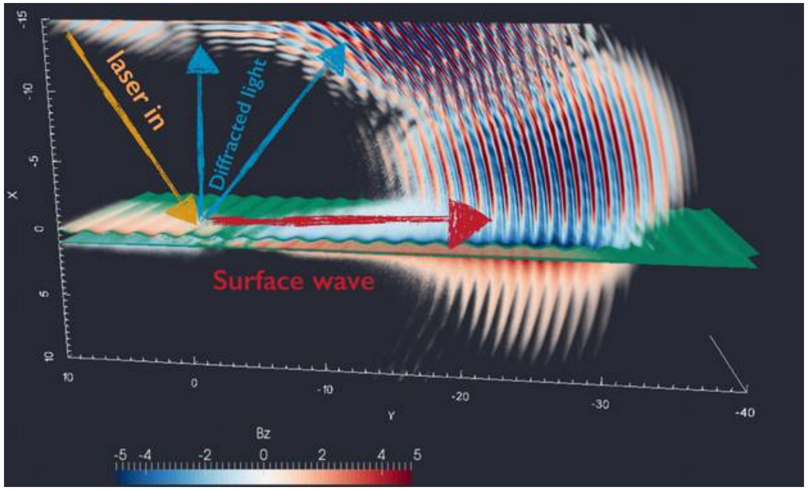
And why should I use a gradient as a target?





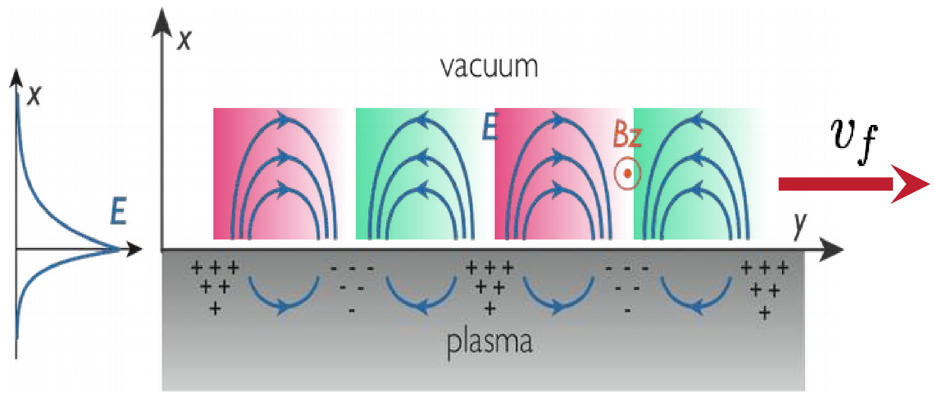
HHG with irradiated solid targets

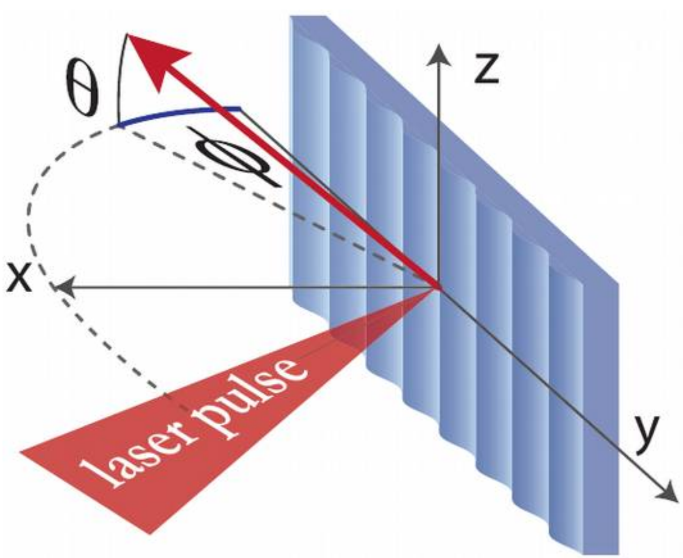
HHG with gratings



Grating targets irradiated
At resonance angle for surface plasmon excitation

With a grating we can satisfy a condition for surface wave coupling

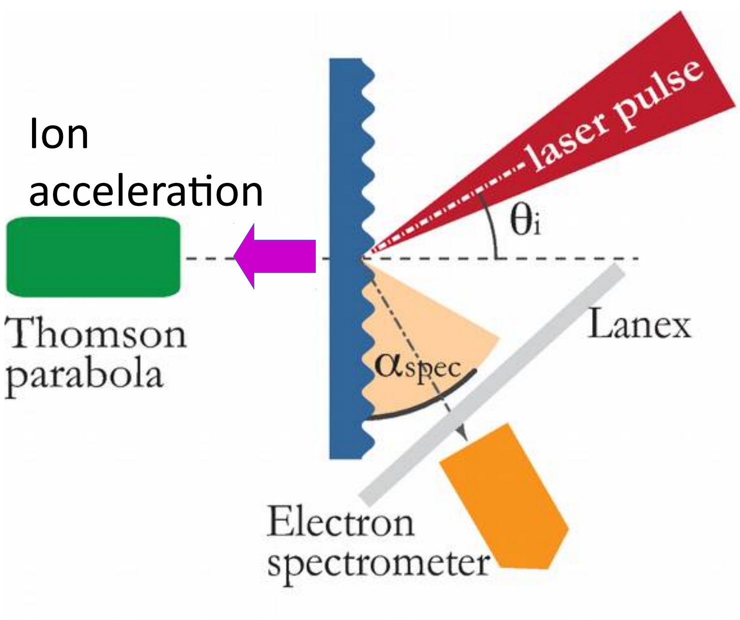


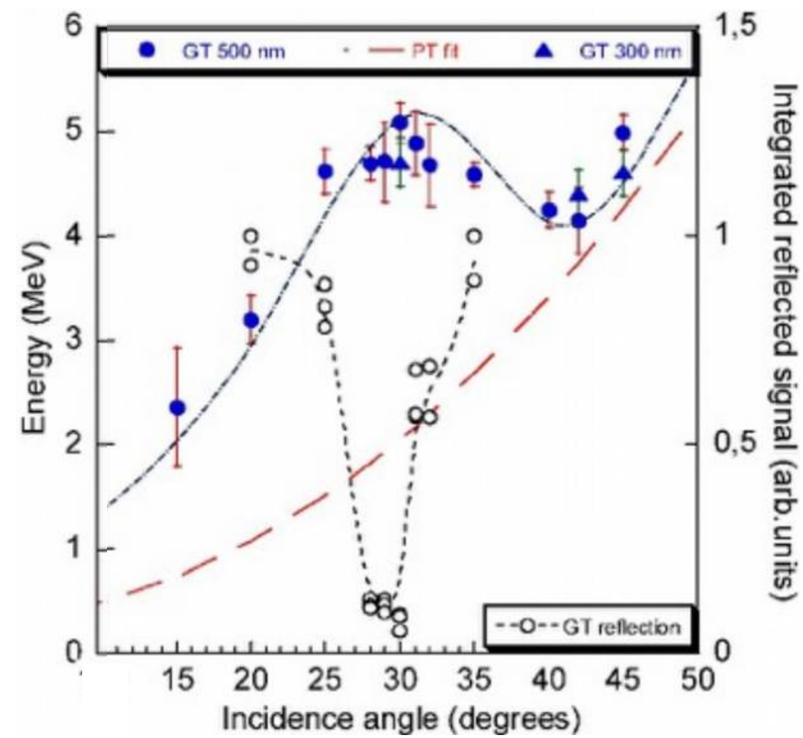


$$\frac{\omega}{c}\sin(\theta)=\frac{\omega}{c}\sqrt{\frac{1-\omega_p^2/\omega^2}{2-\omega_p^2/\omega^2}}\pm n\frac{2\pi}{d}$$

$$\omega \ll \omega_p \rightarrow \frac{\omega}{c}\sin(\theta)\approx\frac{\omega}{c}\pm n\frac{2\pi}{d}$$

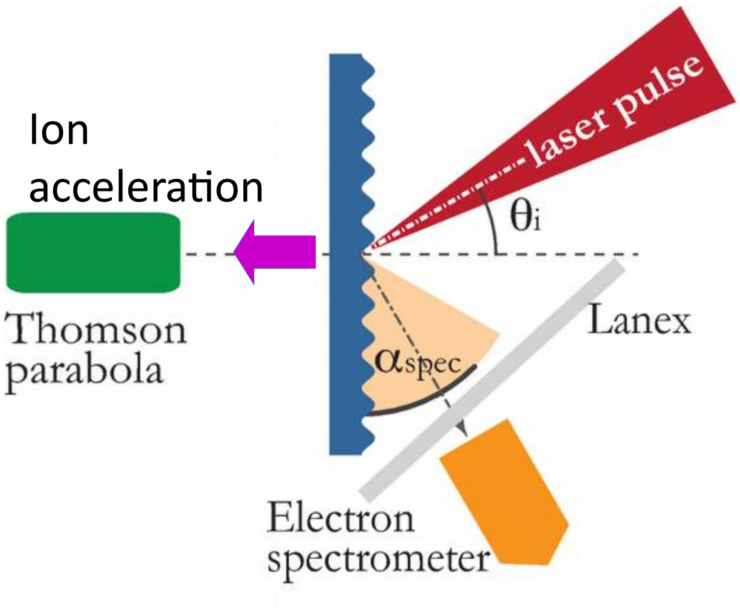
Resonant enhancement of laser-driven ion acceleration

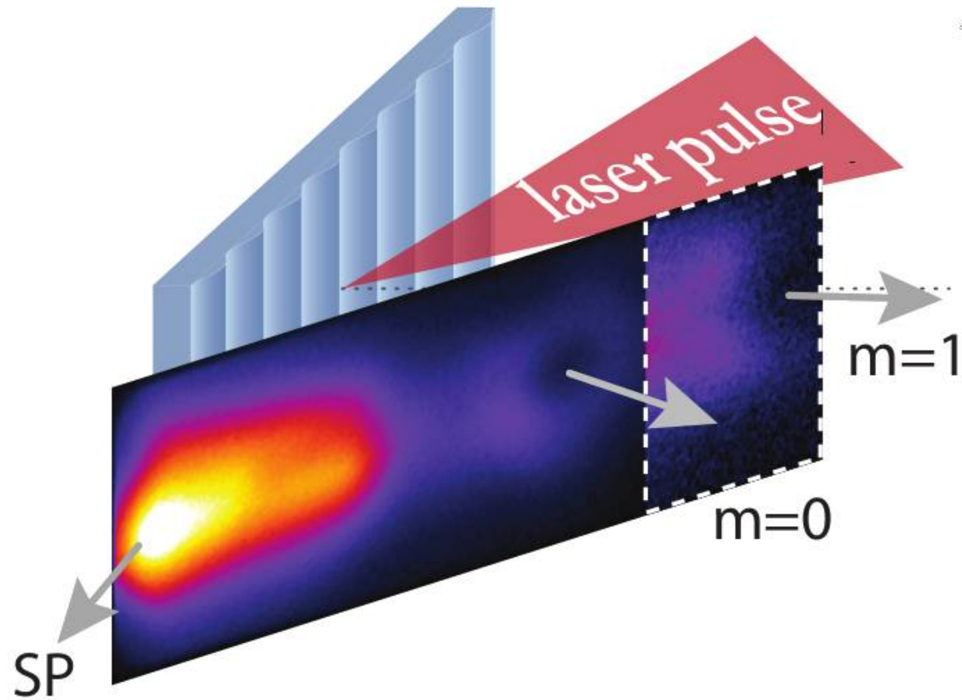




Ceccotti et al. PRL 111 (2013)

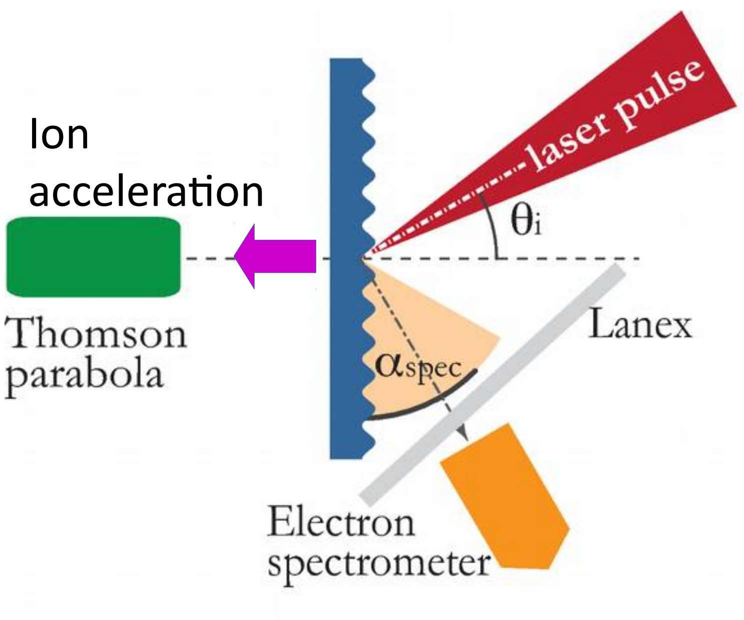
Emission of collimated electron bunches along the target surface

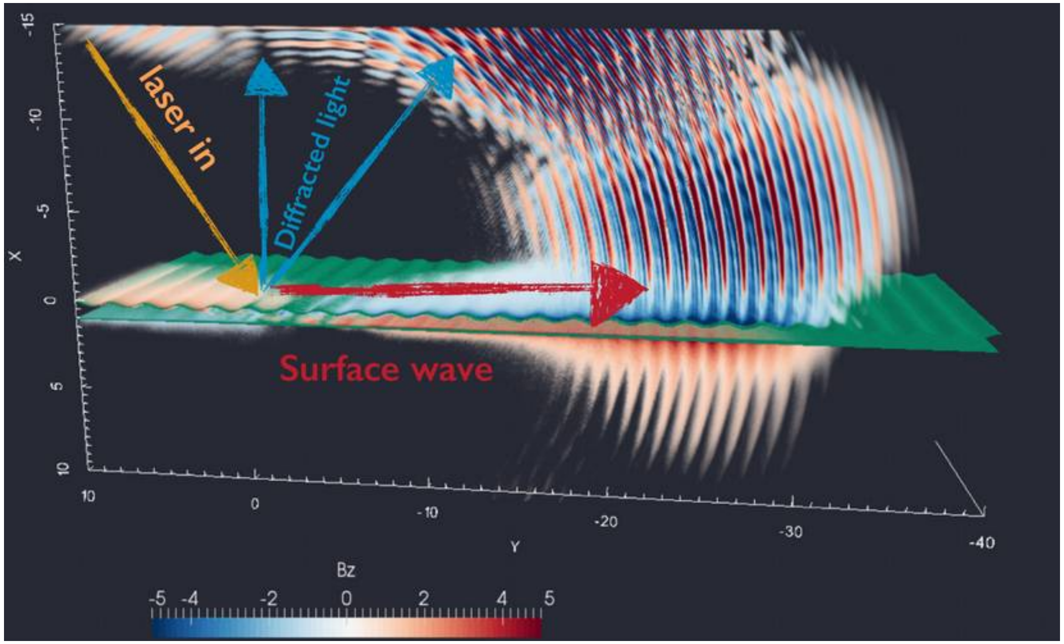




Fedeli et al. PRL 2016
Sgattoni et al. PPCF 2016

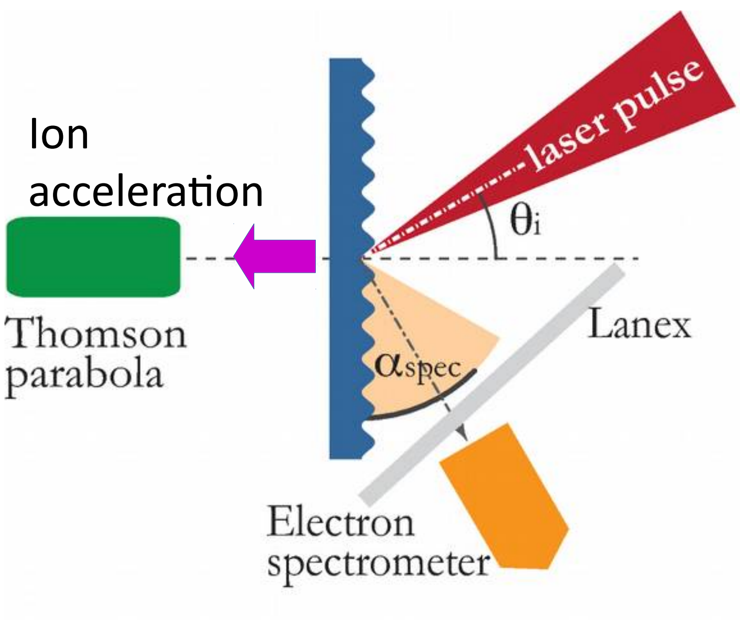
Emission of collimated electron bunches along the target surface

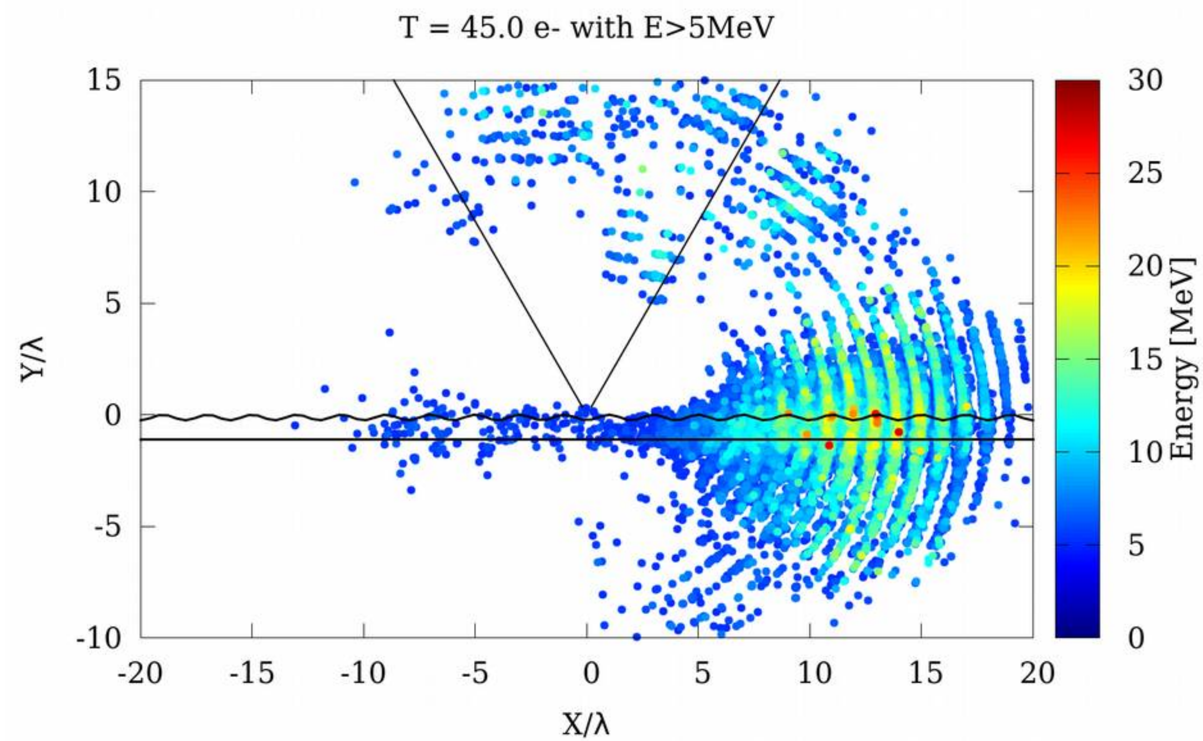




Fedeli et al. PRL 2016
Sgattoni et al. PPCF 2016

Emission of collimated electron bunches along the target surface

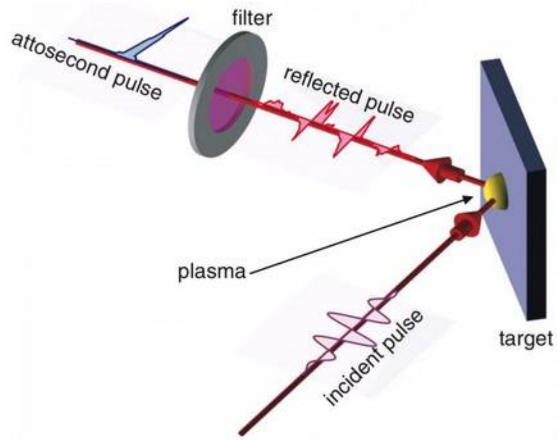


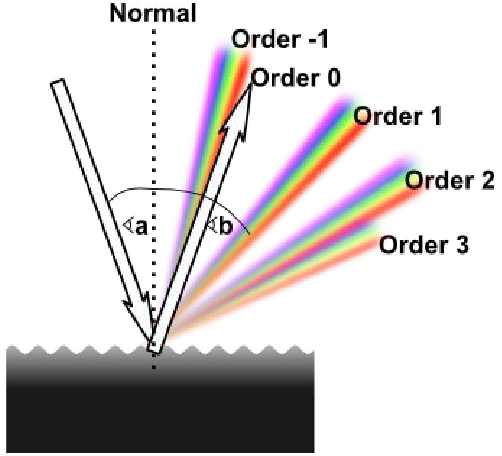


Fedeli et al. PRL 2016
Sgattoni et al. PPCF 2016

Riconda et al. PoP 2015

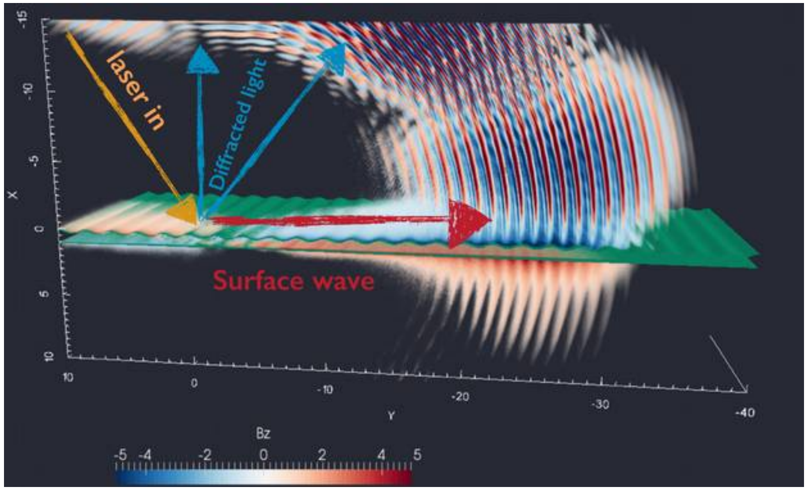
We combine these three ingredients





HHG with irradiated solid targets

HHG with gratings

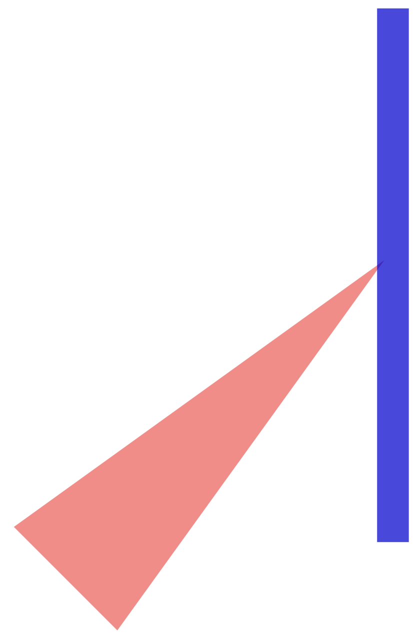


Grating targets irradiated
At resonance angle for surface plasmon excitation

2D numerical simulation campaign

2D numerical simulation campaign

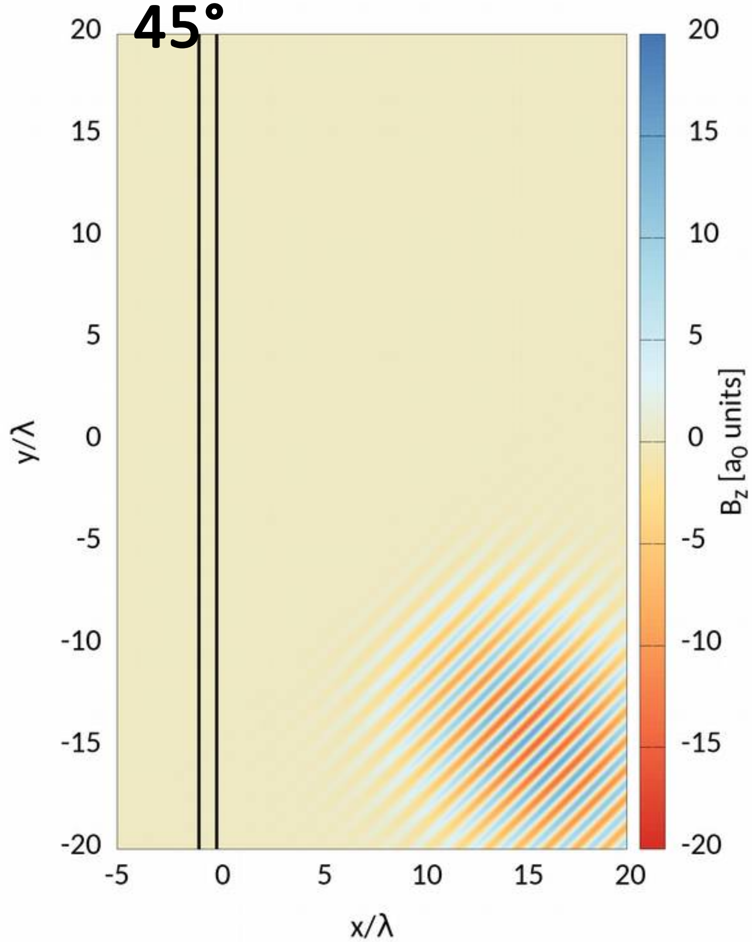
Laser (~100s TW system):
P-pol, $a_0 = 15$,
32 fs FWHM, 4 µm waist



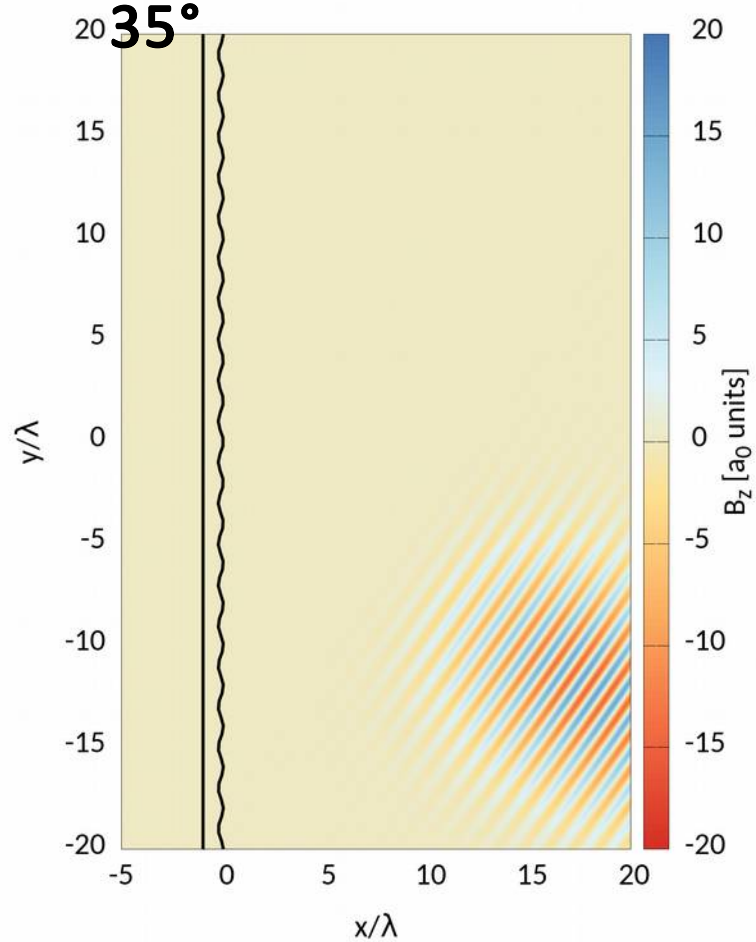
Target:
Either a **flat target** or a **grating target** with d=2.0λ (resonance at 30°) and peak-to-valley depth of 0.25λ

Few snapshots of the EM fields

Flat target @ 45°



Grating target @ 35°



Few snapshots of the EM fields

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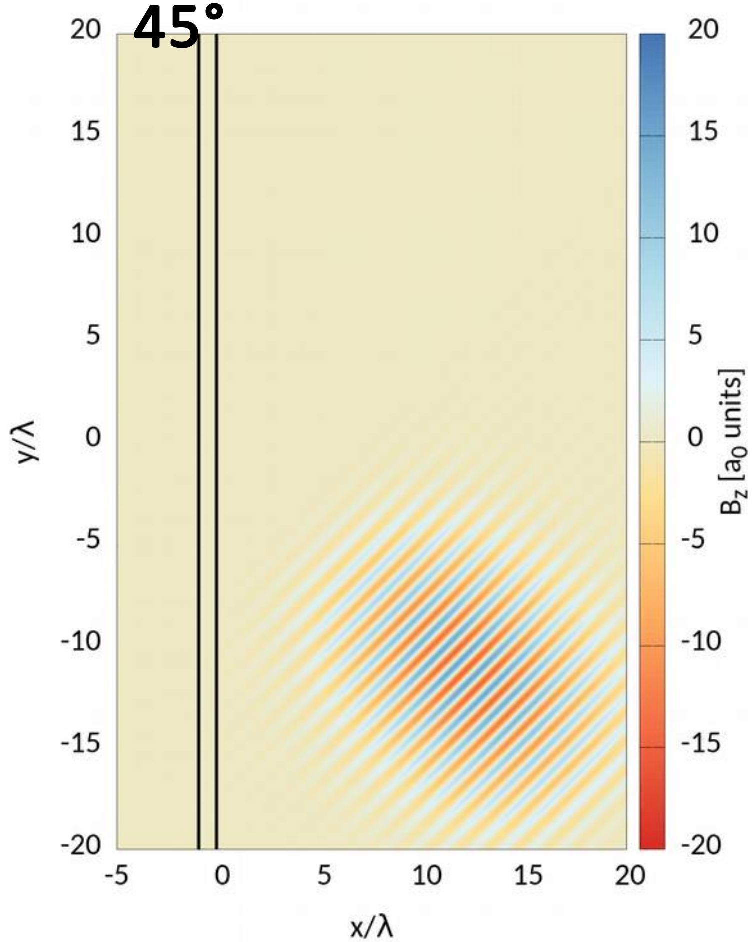
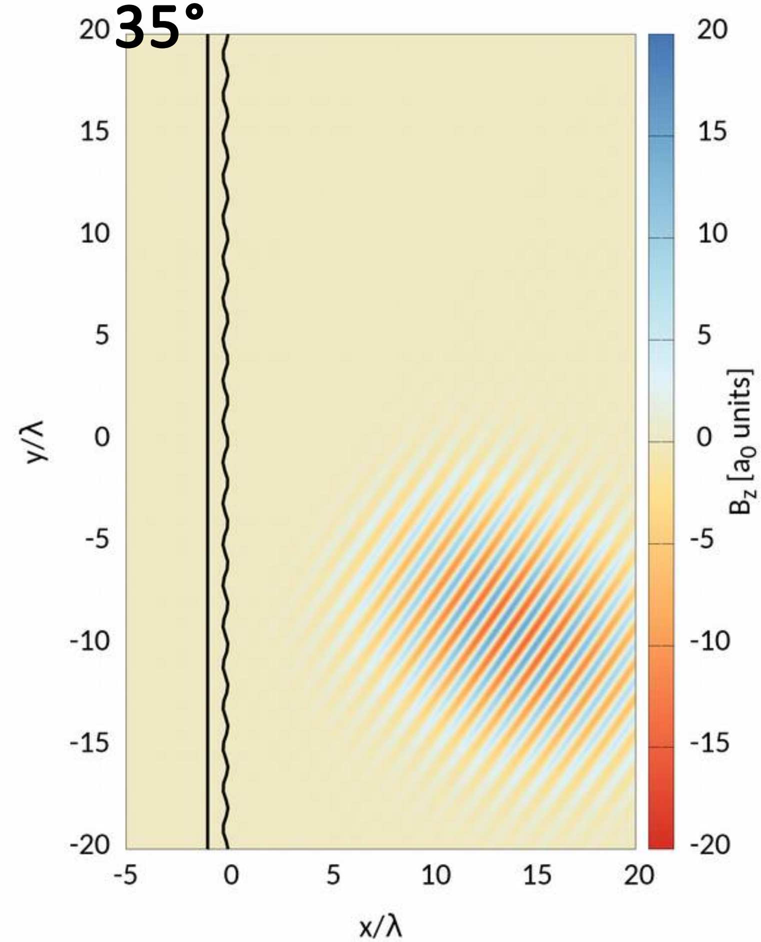


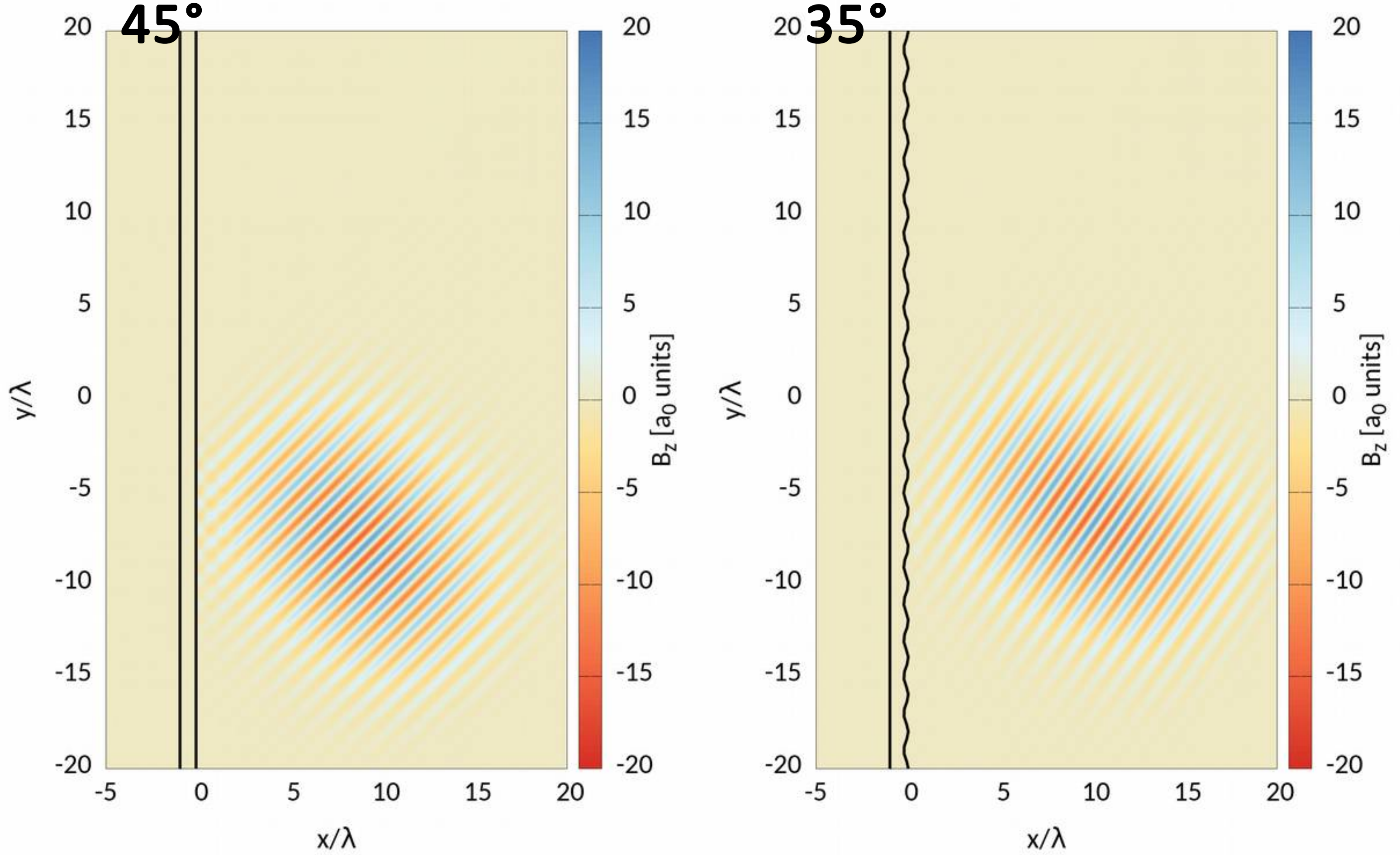
Grating target @ 35°



Few snapshots of the EM fields

Flat target @ 45°

Grating target @ 35°



Few snapshots of the EM fields

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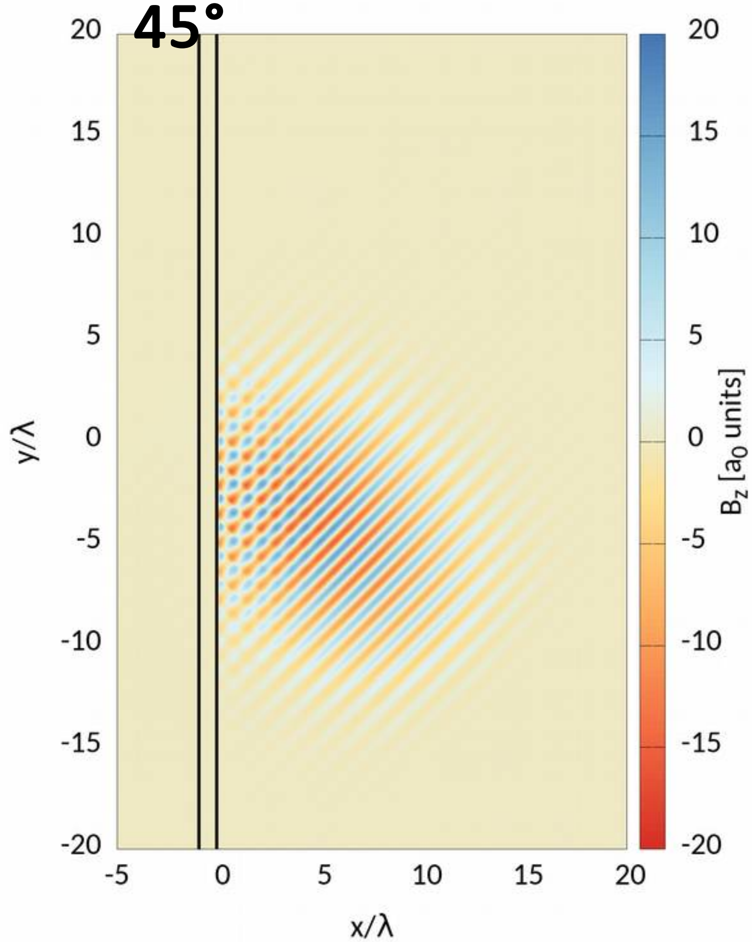
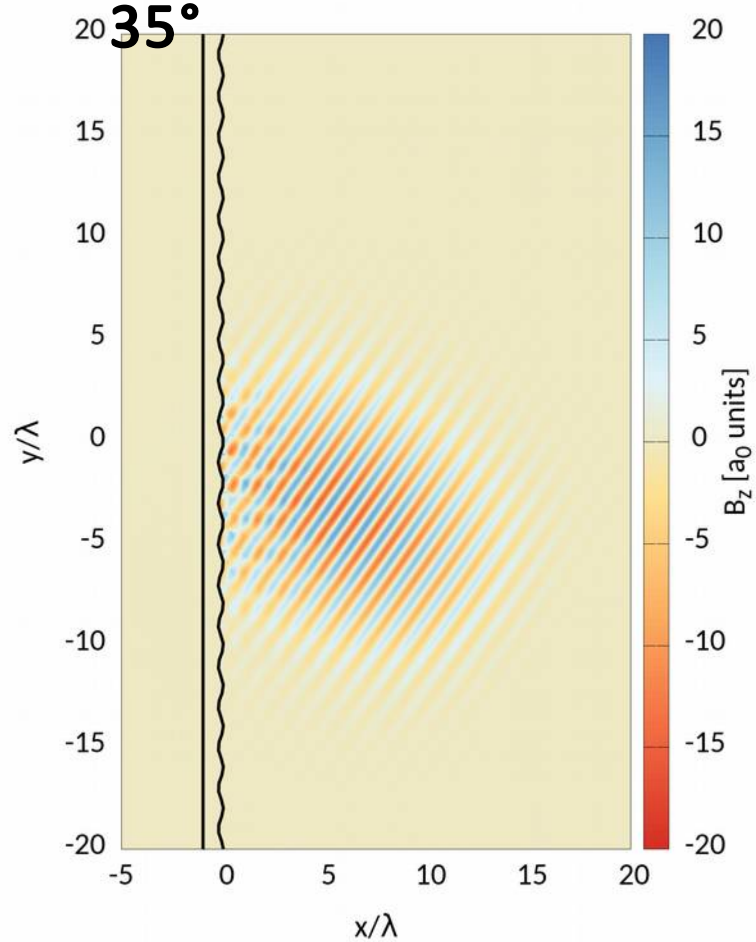


Grating target @ 35°



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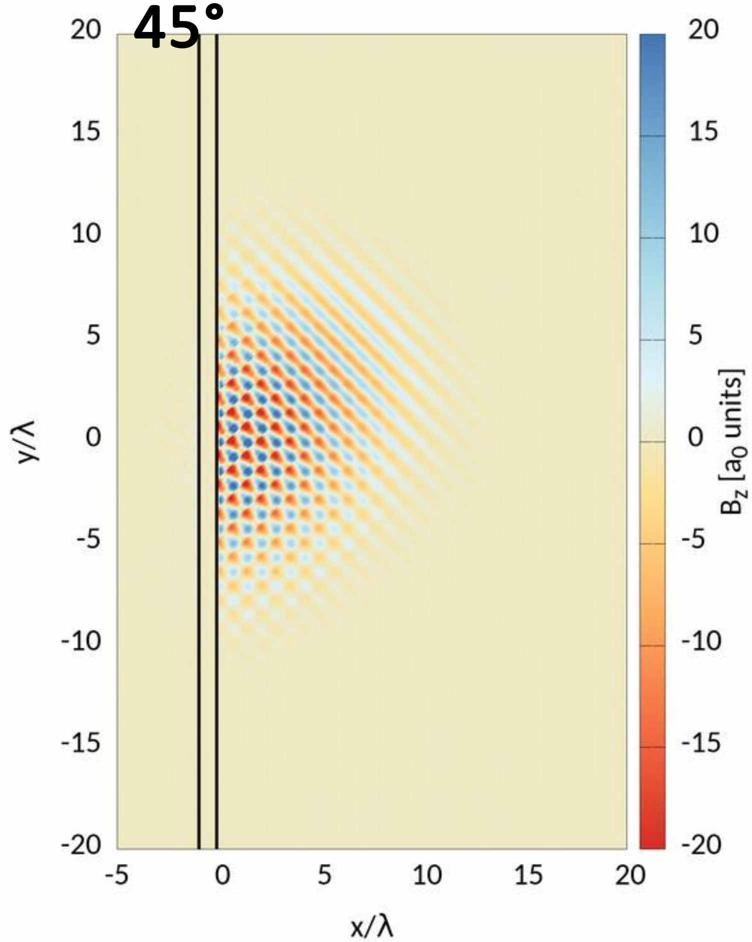
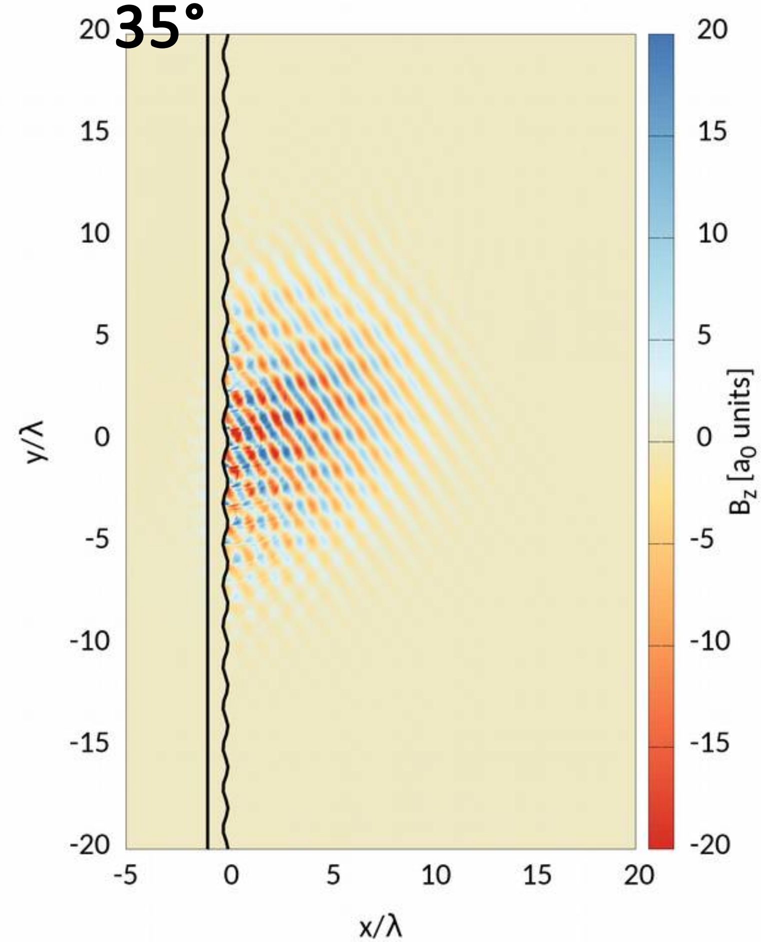


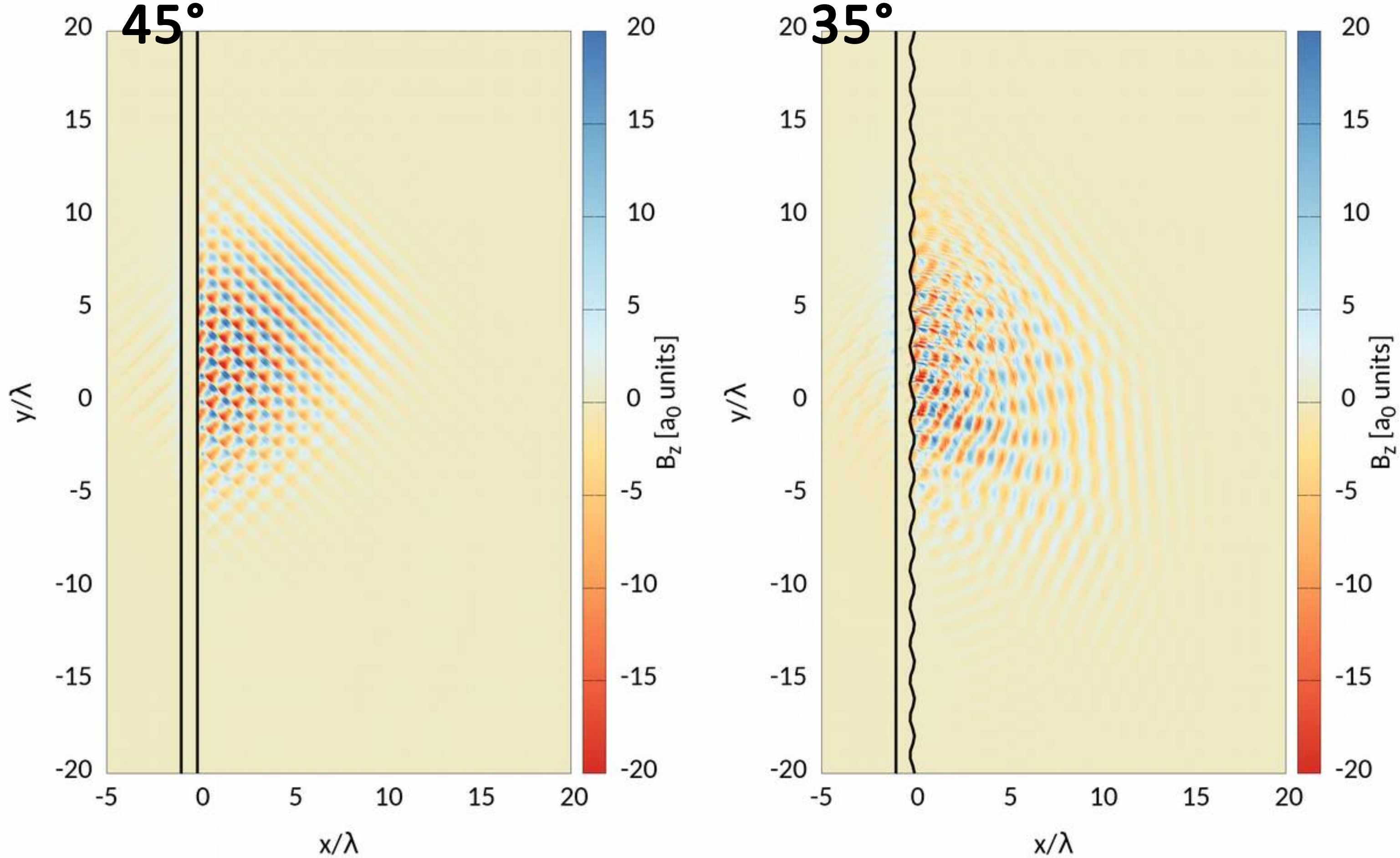
Grating target @ 35°



Few snapshots of the EM fields

Flat target @ 45°

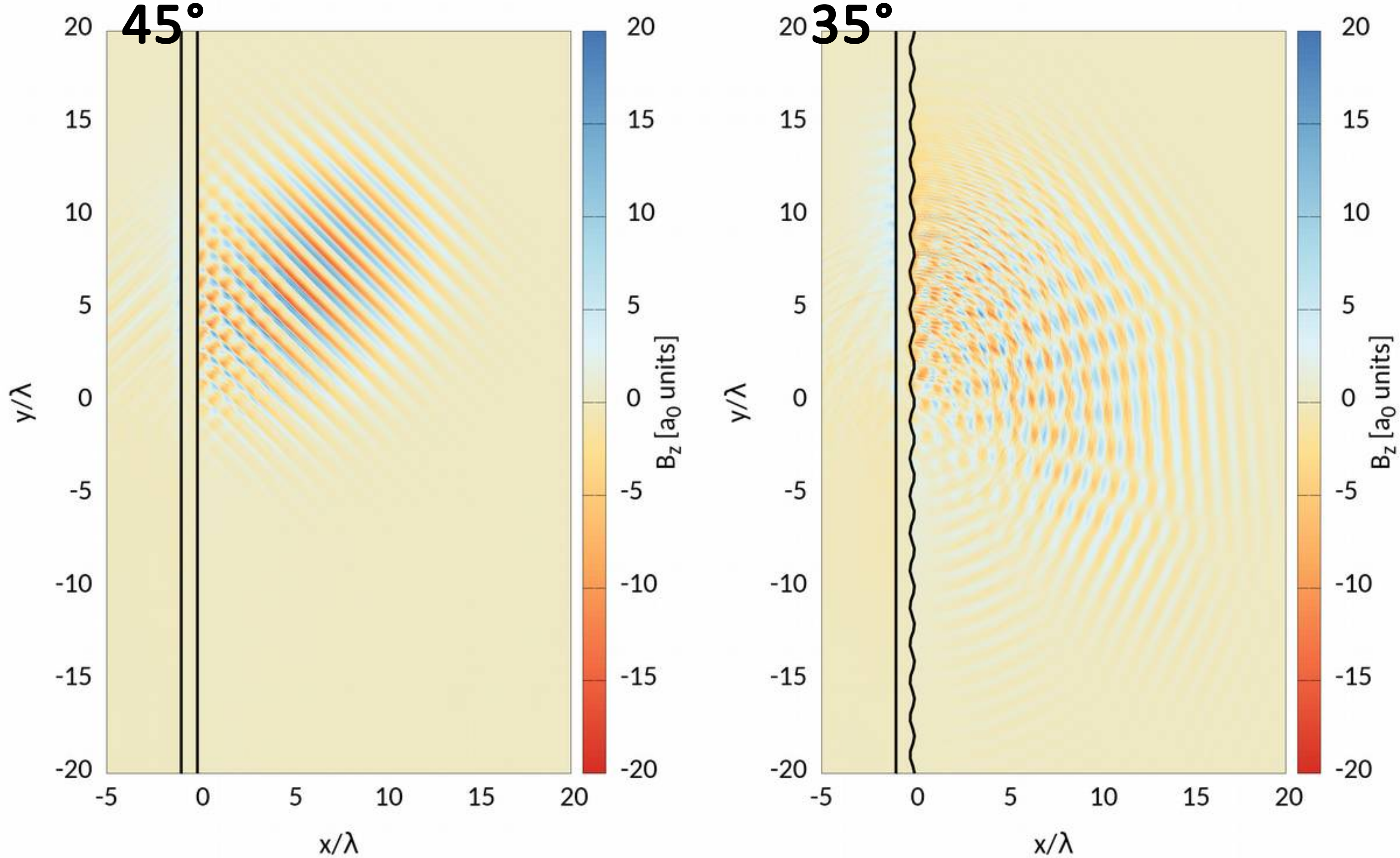
Grating target @ 35°



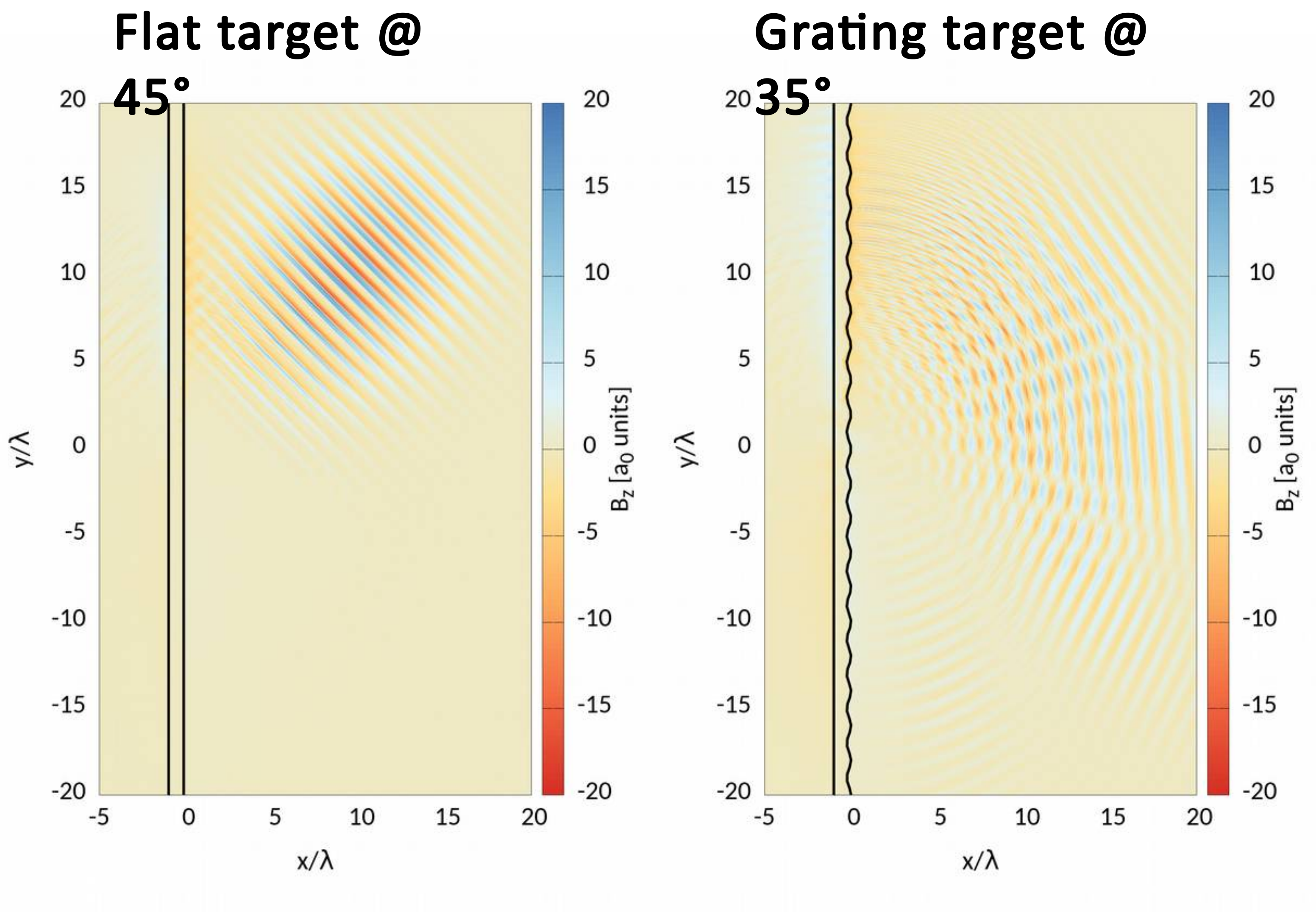
Few snapshots of the EM fields

Flat target @ 45°

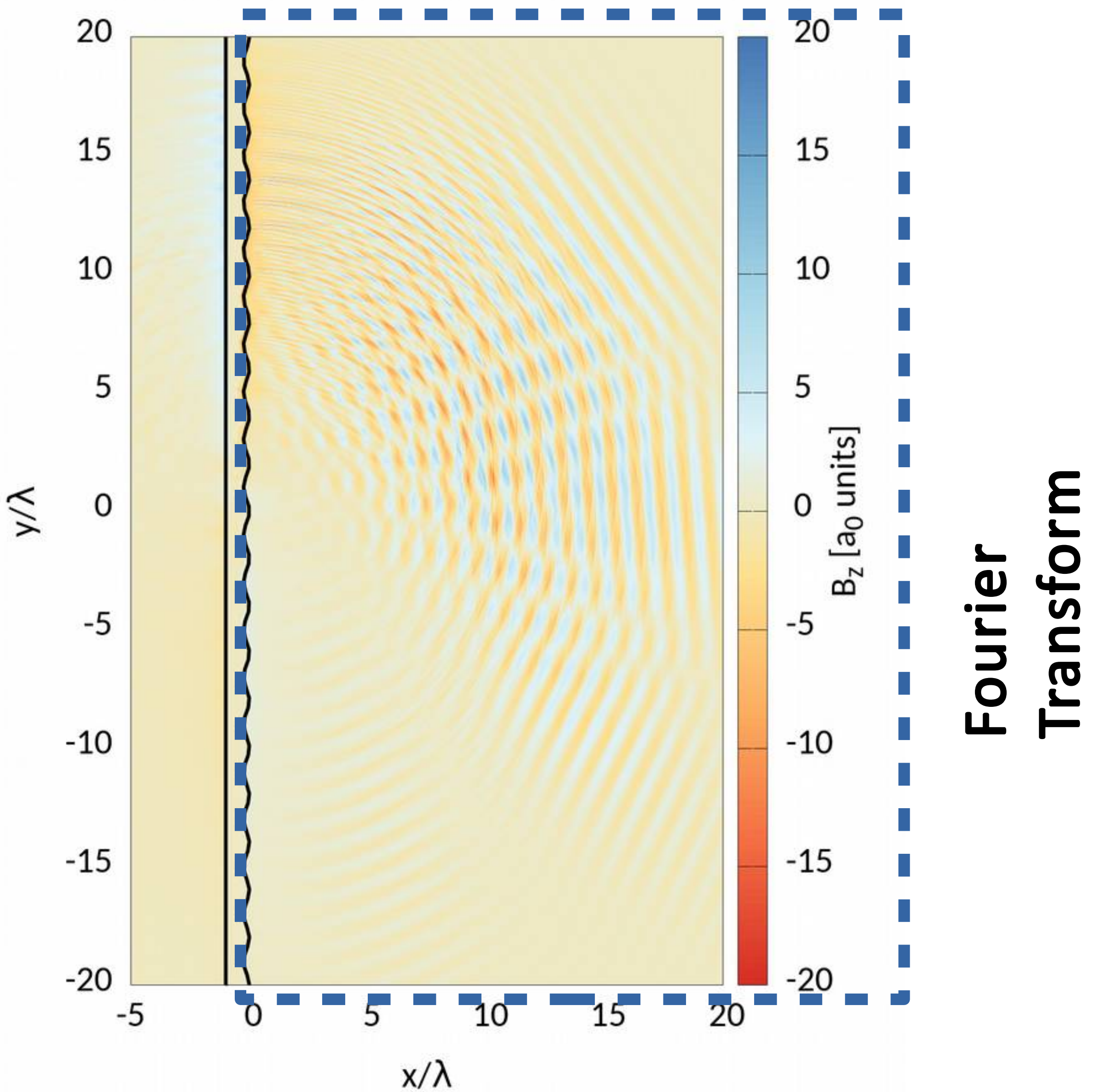
Grating target @ 35°



Few snapshots of the EM fields



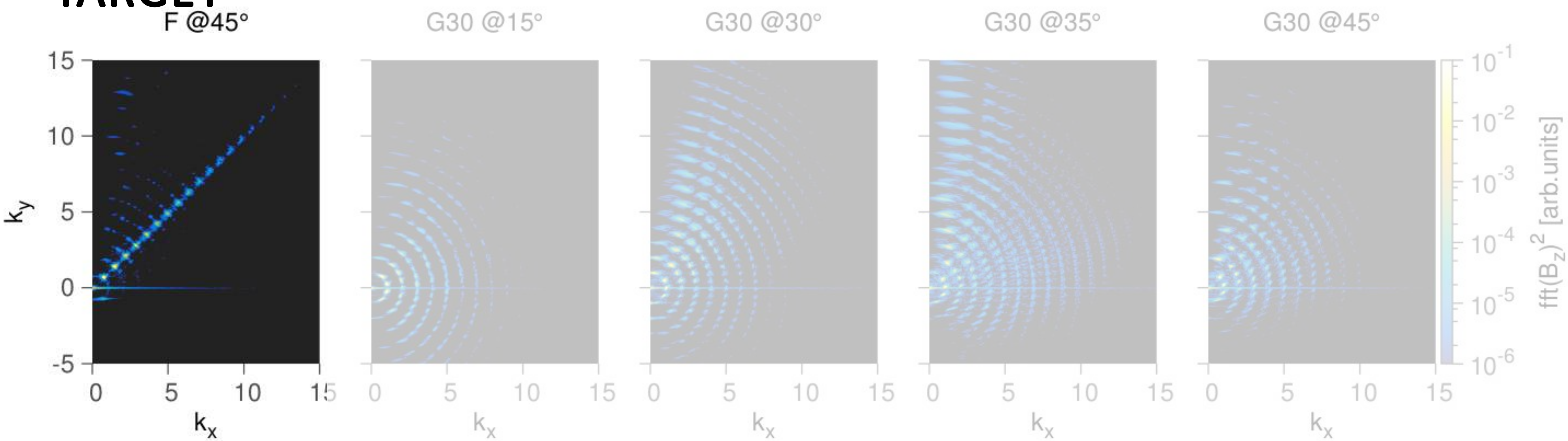
Fourier transform of B_z



Enhancement of HHG near-resonance

FLAT TARGET

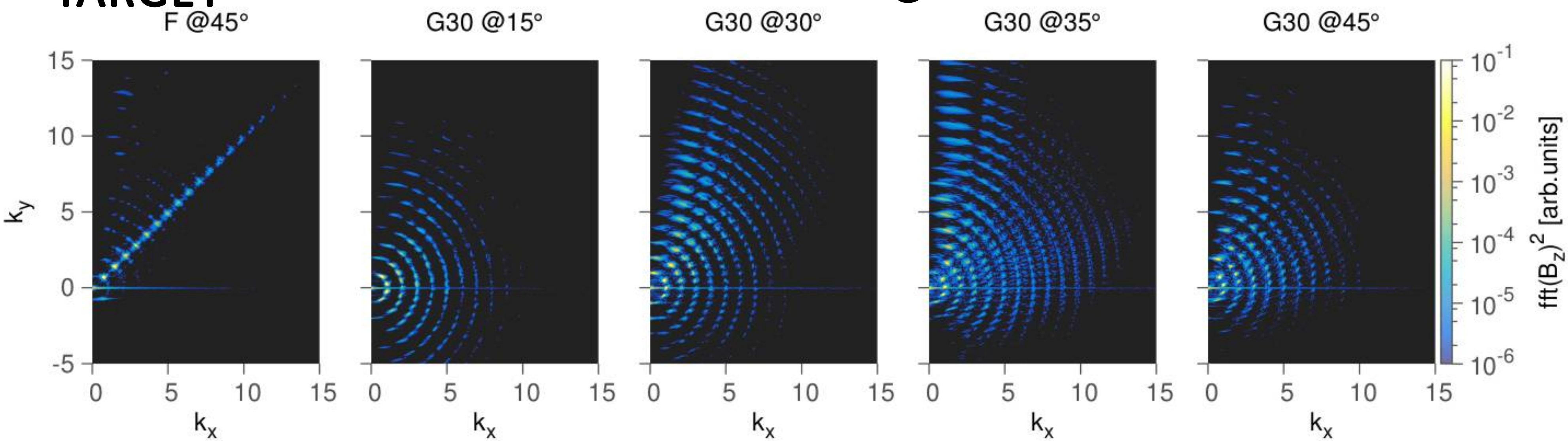
GRATIN



Enhancement of HHG near-resonance

FLAT TARGET

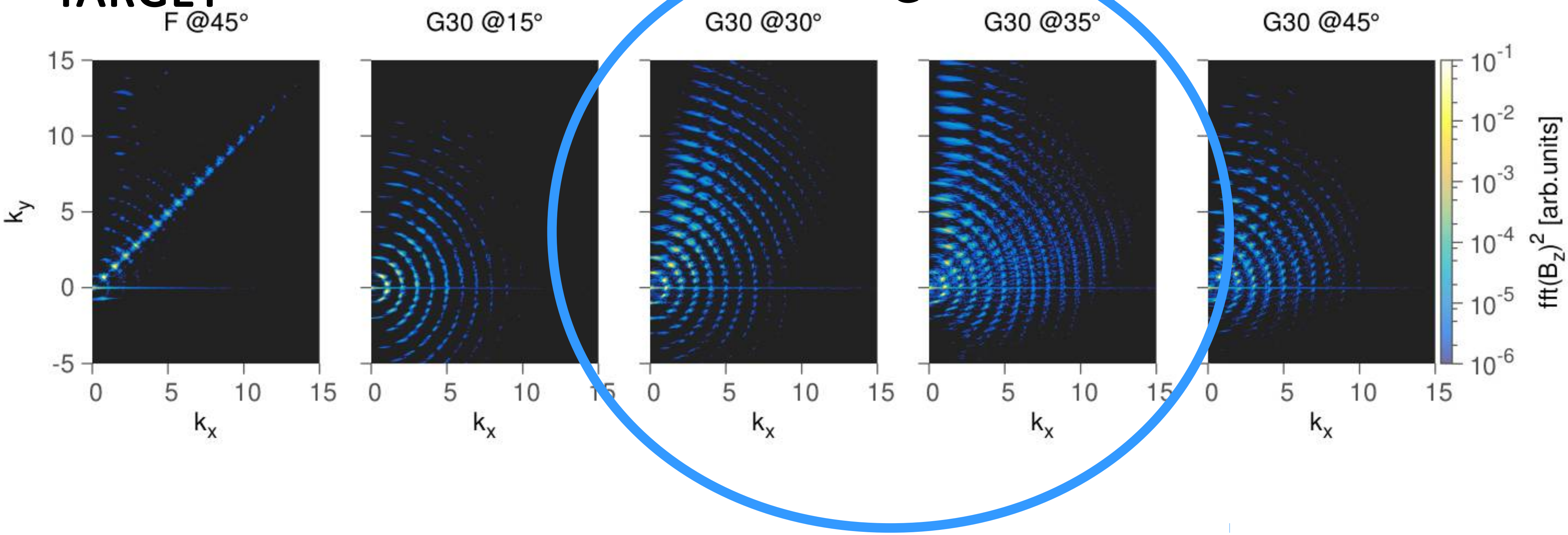
GRATIN G



Enhancement of HHG near-resonance

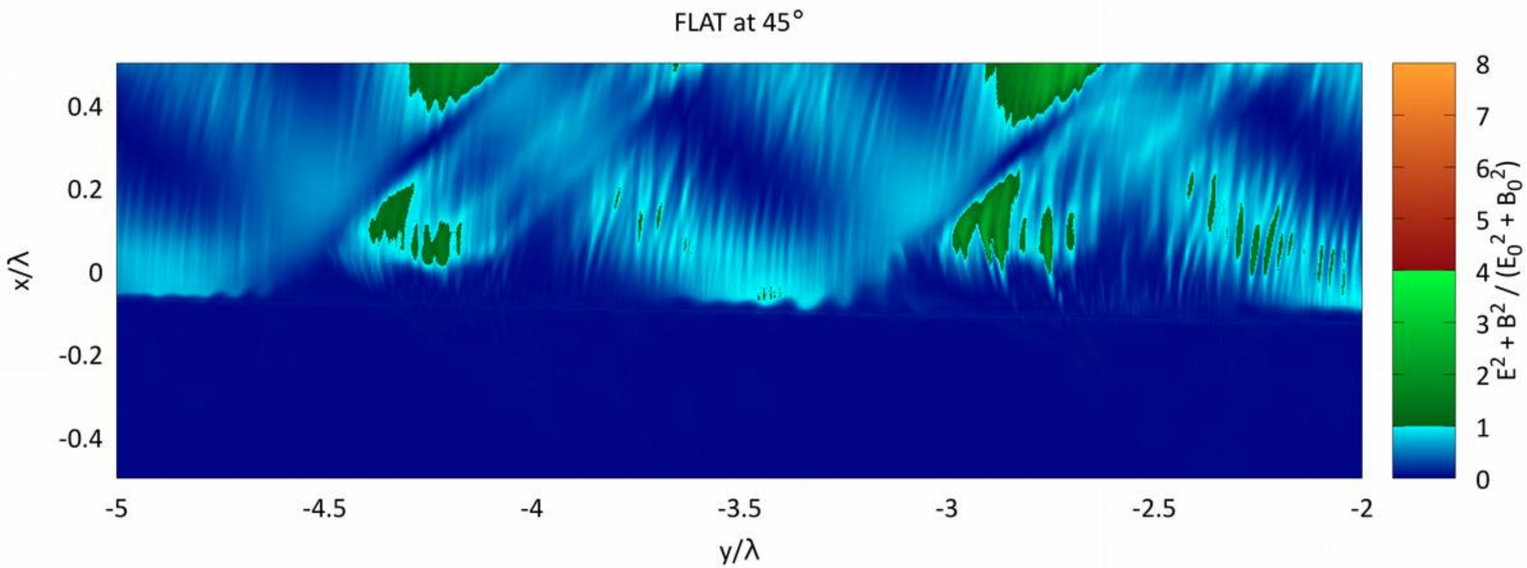
FLAT TARGET

GRATIN G

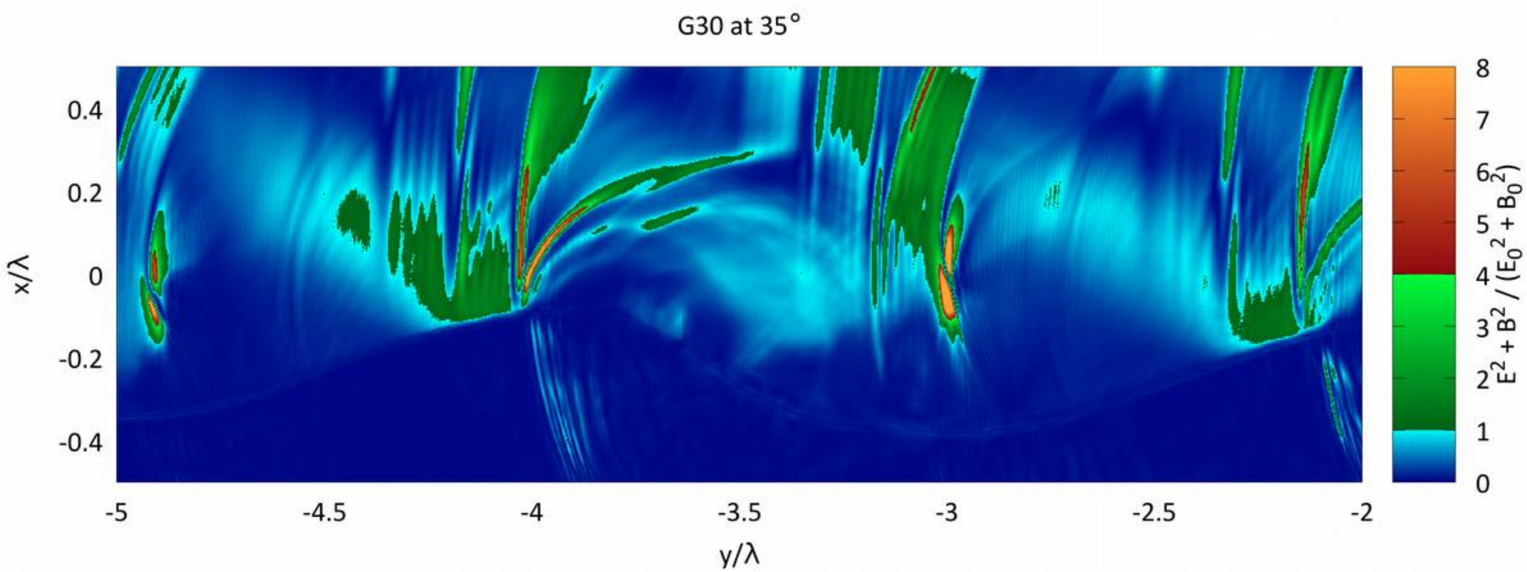


Field enhancement at the target surface

FLAT TARGET



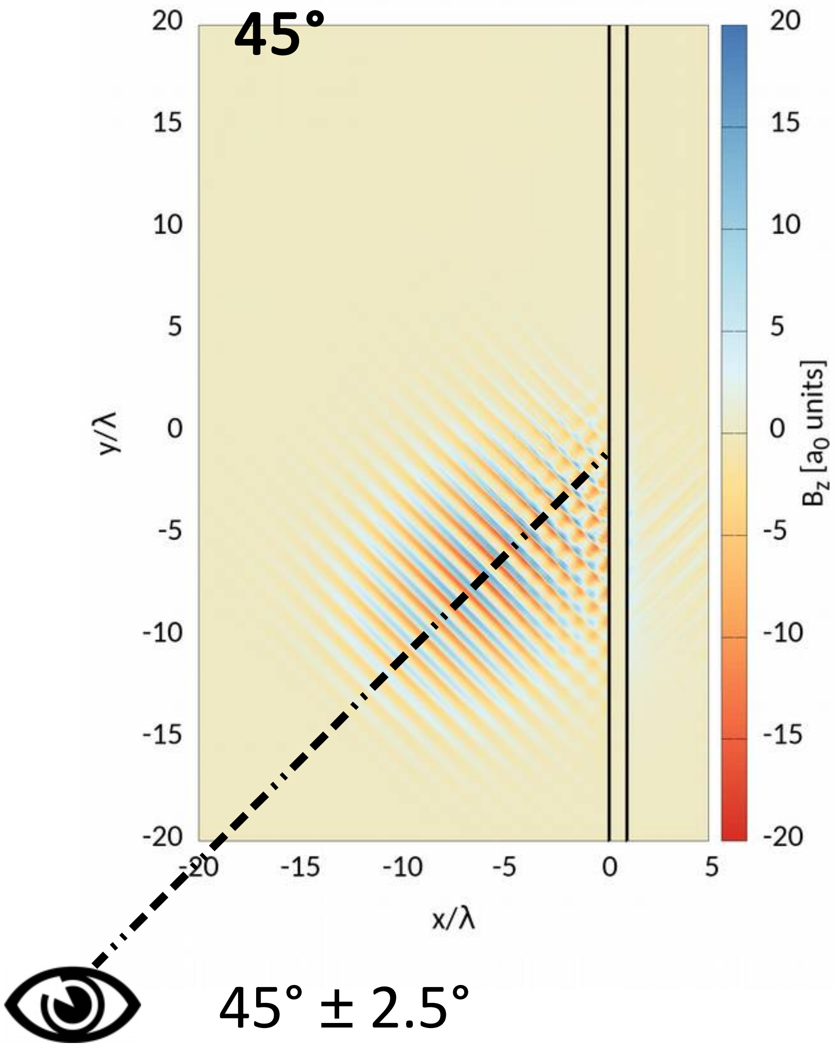
GRATING @ RESONANCE



What would a real, finite-size detector would see?

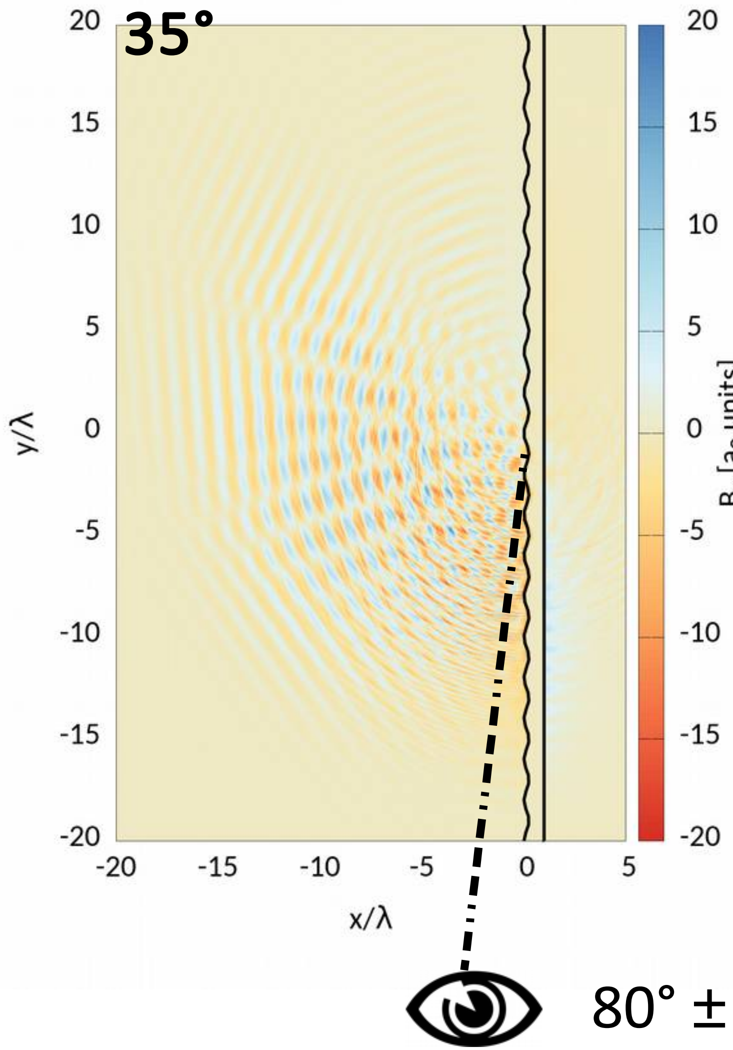
What would a real, finite-size detector would see?

Flat target @ 45°



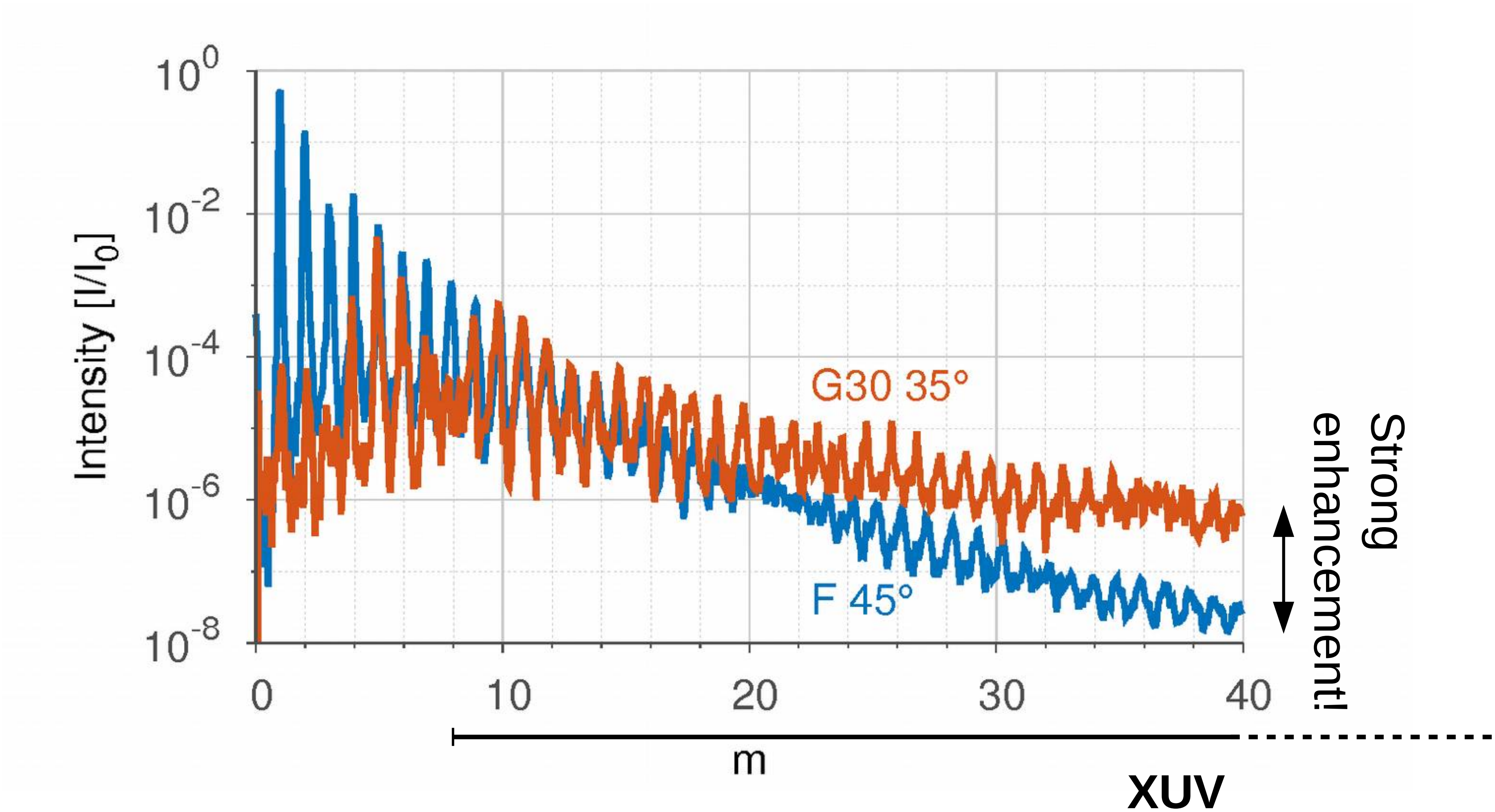
45° ± 2.5°

Grating target @ 35°

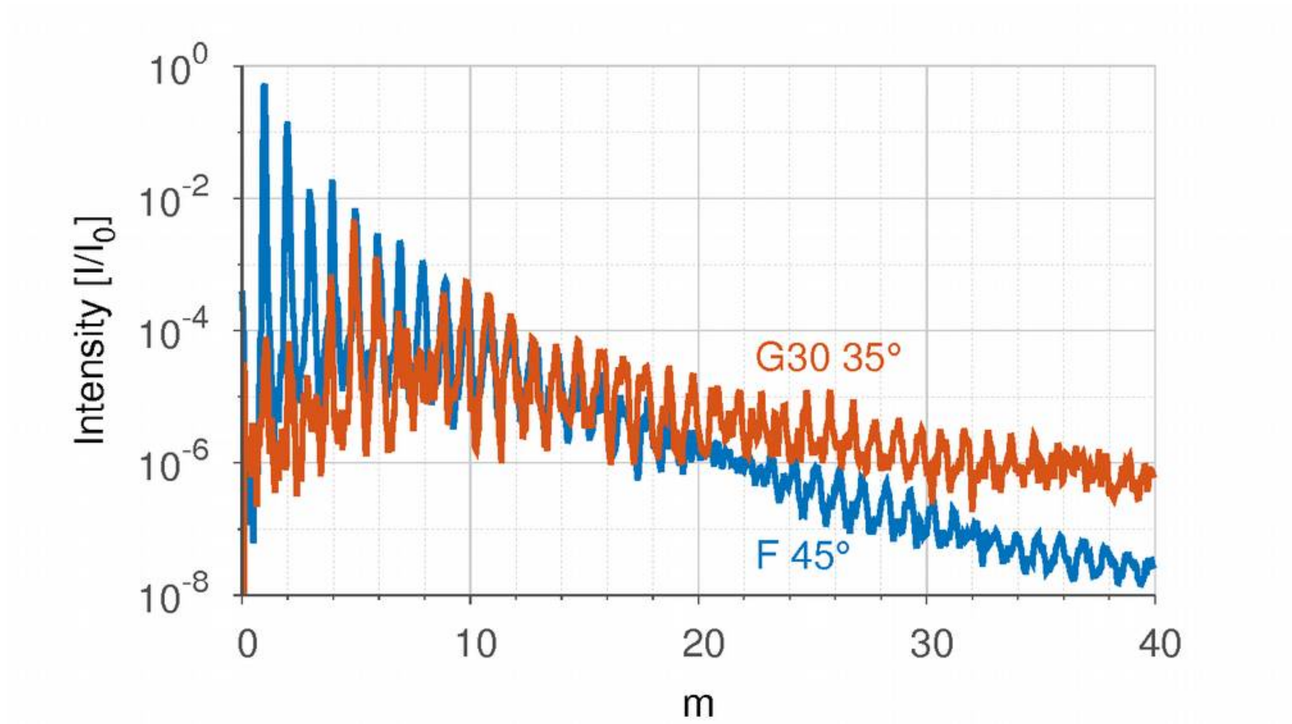


80° ± 2.5°

What would a real, finite-size detector would see?

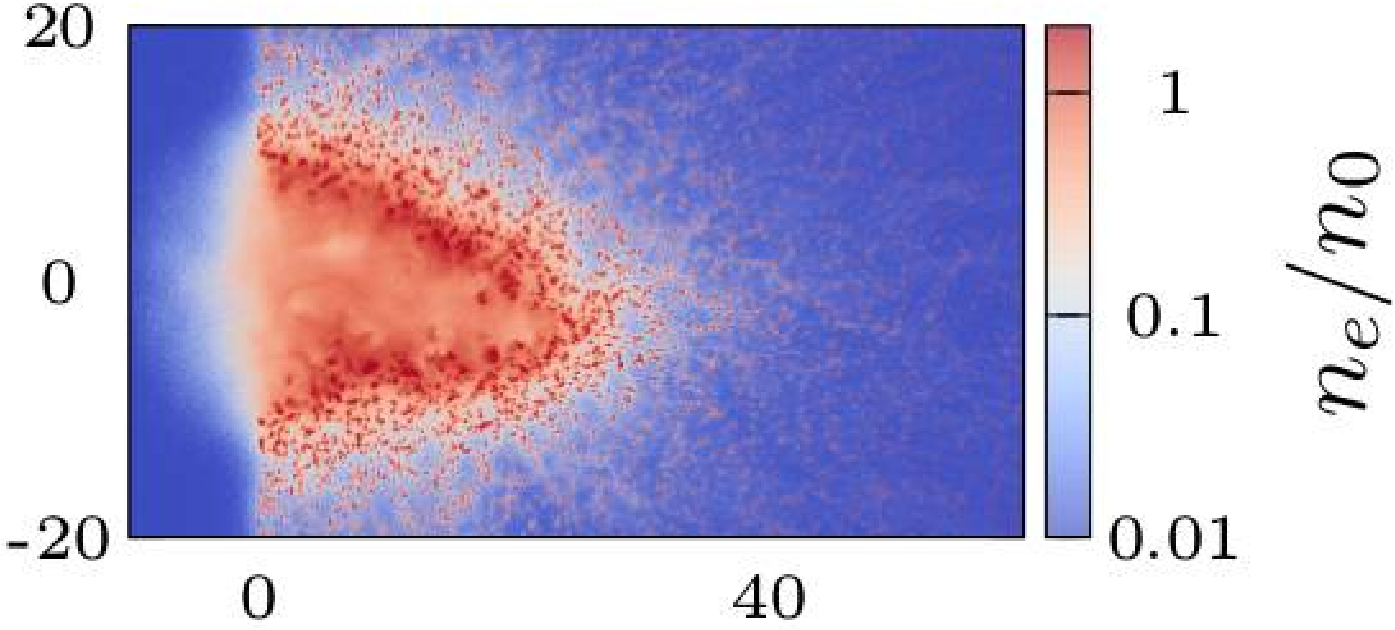


Take home message

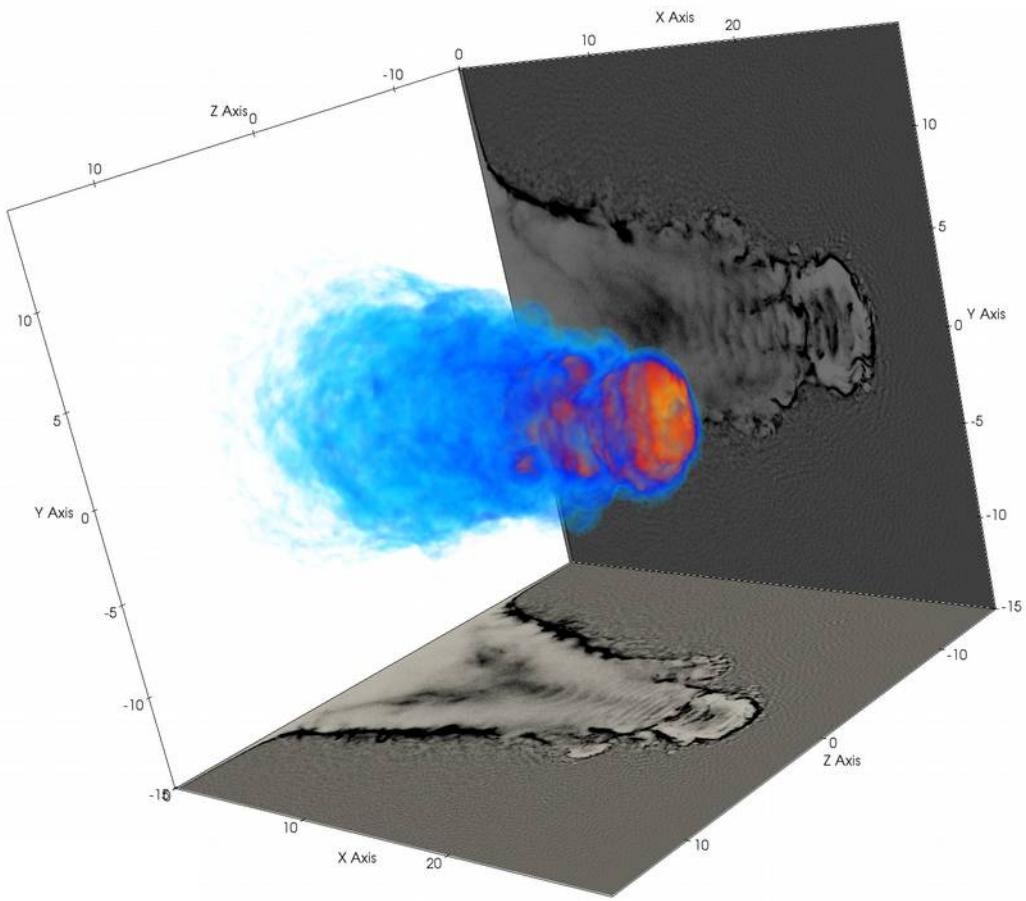


Numerical simulations suggest that irradiating a grating target at the resonance angle for surface plasmon excitation should lead to the generation of higher-order harmonics with respect to simple flat targets

Nanostructured near-critical plasmas



Laser interaction with near-critical plasmas is interesting for several applications...



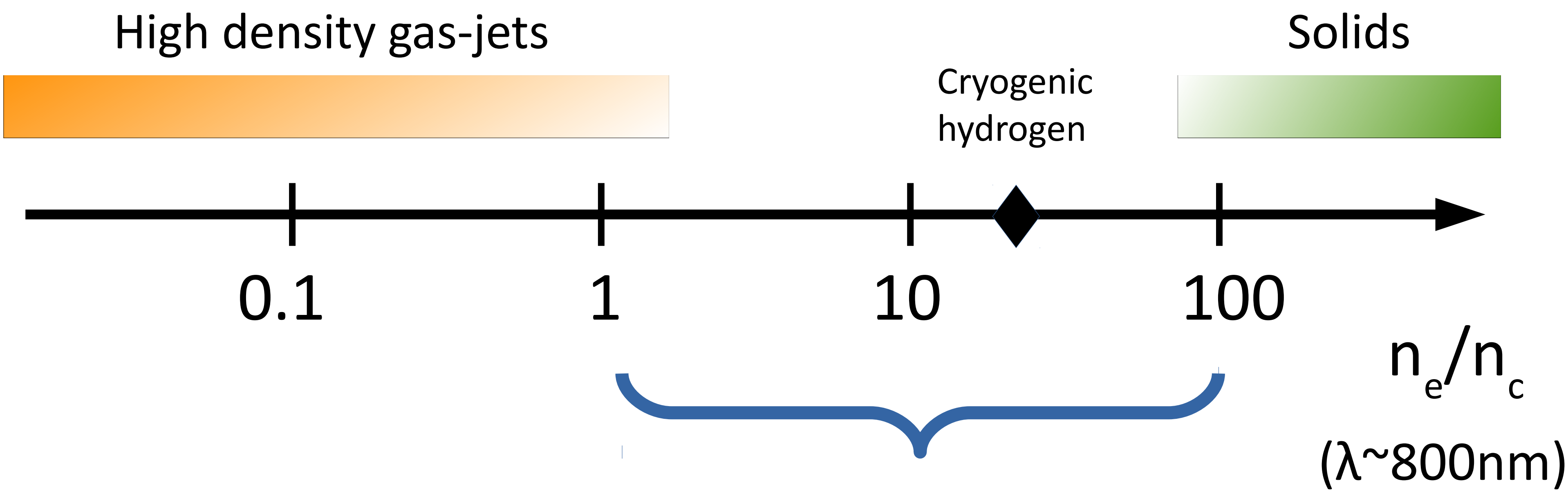
Why bother with near-critical plasmas?

Several interesting applications:

- Enhanced ion acceleration
- Laboratory astrophysics
- γ-ray sources
- Inertial confinement fusion
- Electron acceleration

  ...

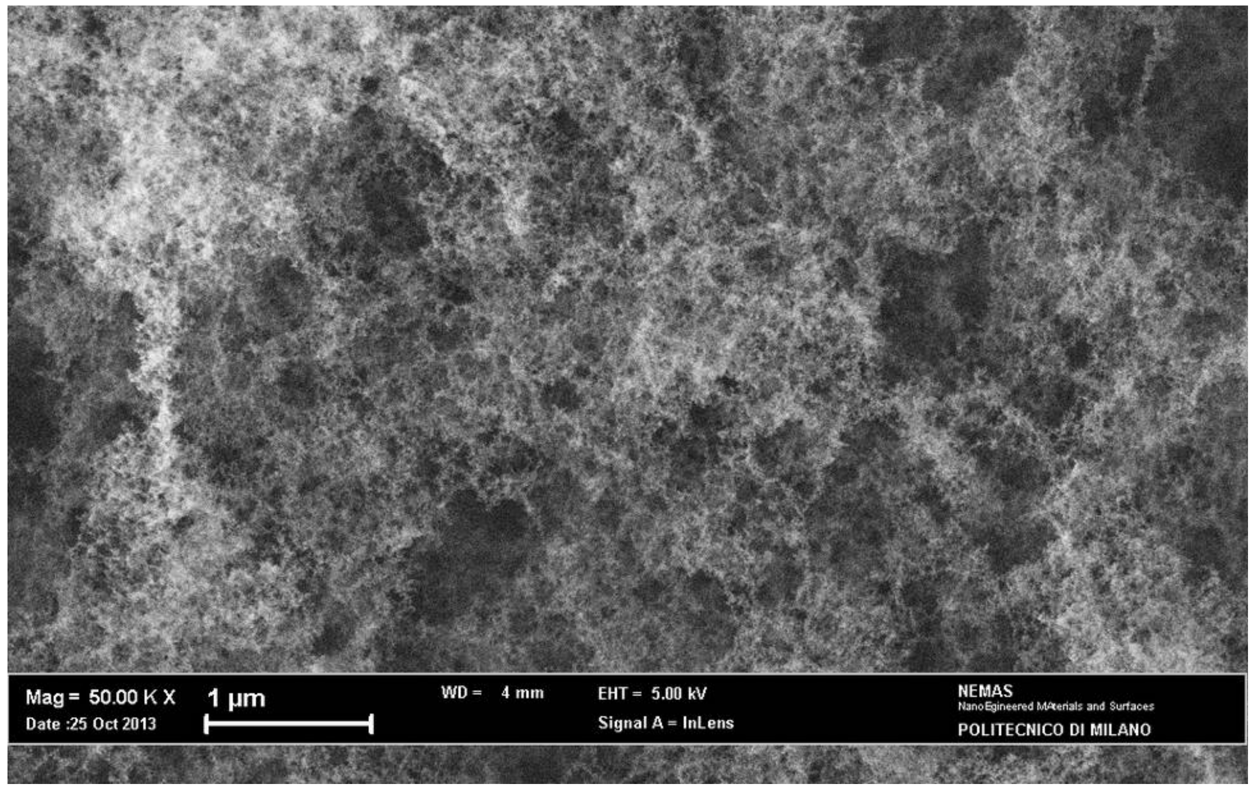
...but they are challenging from a “targetry” point of view!



How do we fill the gap?

- Pre-heating
- **Very low-density nanostructured materials**
  - Aerogels
  - Nanotube arrays
  - **Foams**

Foam has a porous, complex nanostructure



D. Dellasega

A. Maffini

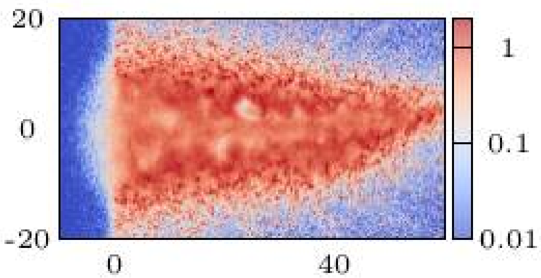
OSAKA UNIVERSITY

We have several ongoing experimental activities involving foam-attached targets

- 2014/2015: enhanced TNSA
- **May 2017**: ion acceleration & physics of irradiated near-critical plasmas
- 2017/2018: collision-less shocks & ps laser interaction with nanostructured foams
- 2017/2018 : pulsed neutron generation
- 2017/2018 : compact ion and neutron sources for materials characterization

ERC-PoC: **INTER**

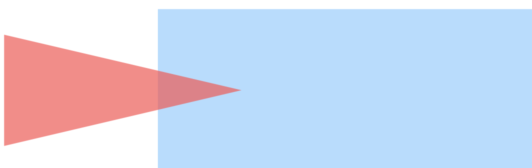
Idealized modeling



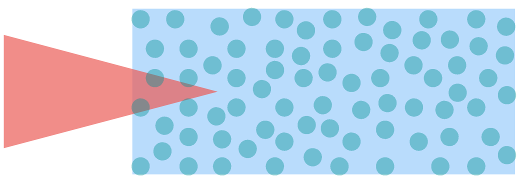
Laser propagation in uniform and nanostructured near-critical plasmas
L.Fedeli, A.Formenti, C.E.Bottani & M.Passoni EPJD Topical Issue on “Relativistic Laser Plasma Interactions” (accepted) 2017

We studied three very idealized plasma models

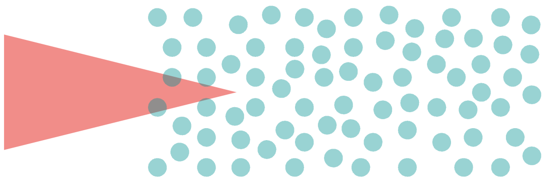
uniform plasmas



“mixed” plasmas



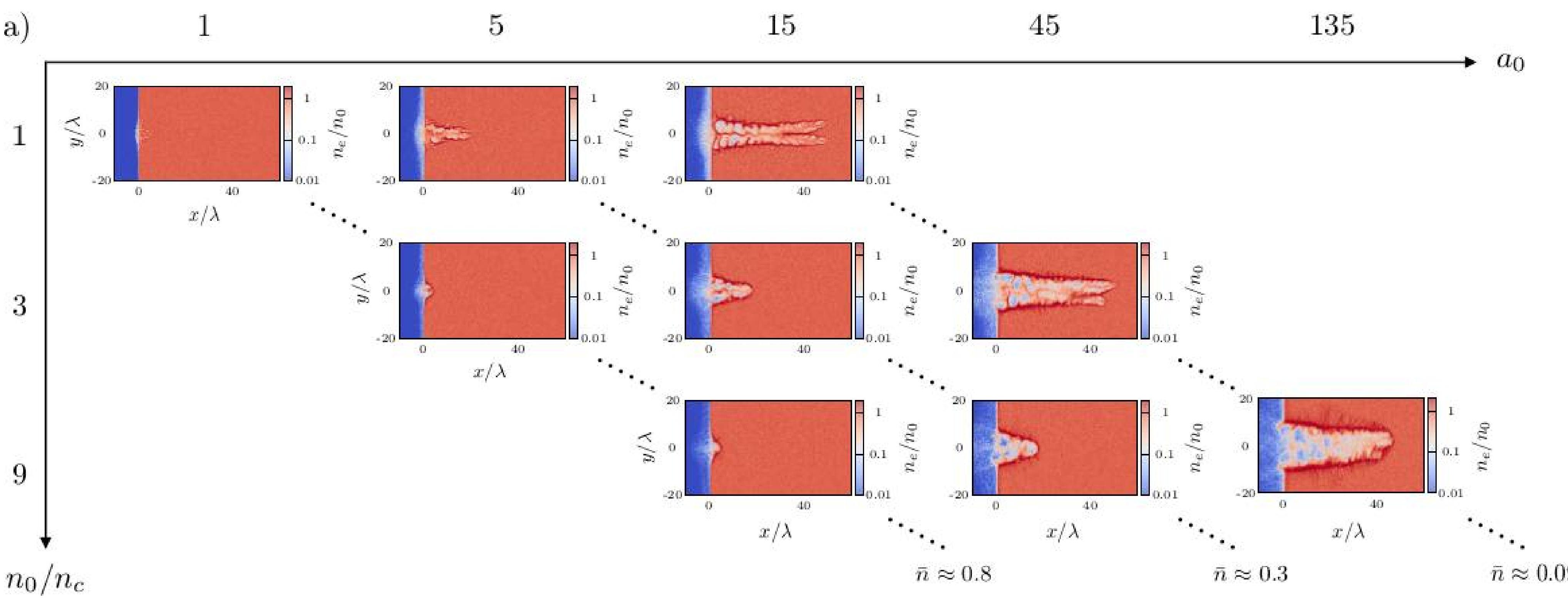
nanostructured plasmas



L.Fedeli, A.Formenti, C.E.Bottani & M.Passoni
EPJD Topical Issue on “Relativistic Laser Plasma Interactions” (accepted) 2017

2D numerical simulation campaign

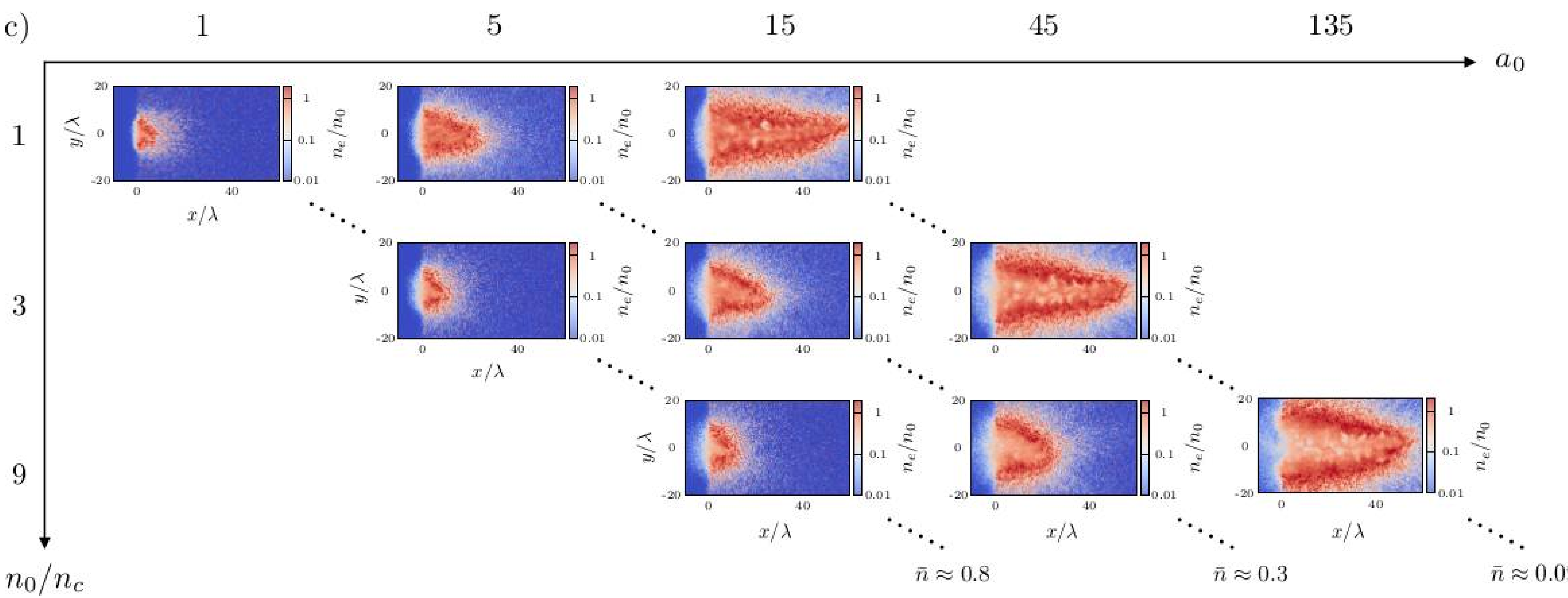
In a wide range of laser intensities and average densities



Uniform plasma

$$\bar{n} = \frac{n_e/n_c}{\sqrt{1+a_0^2/2}}$$

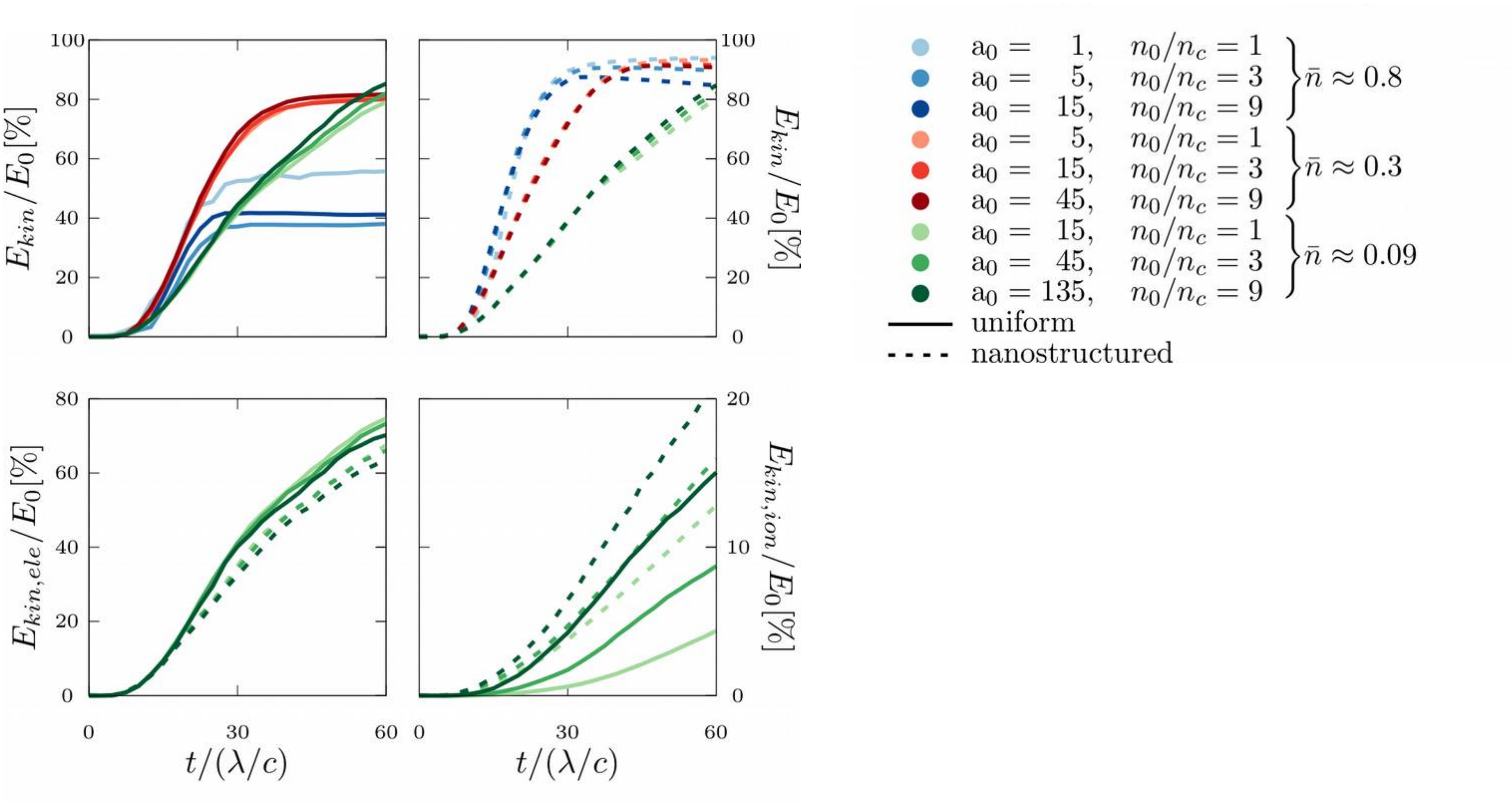
In a wide range of laser intensities and average densities



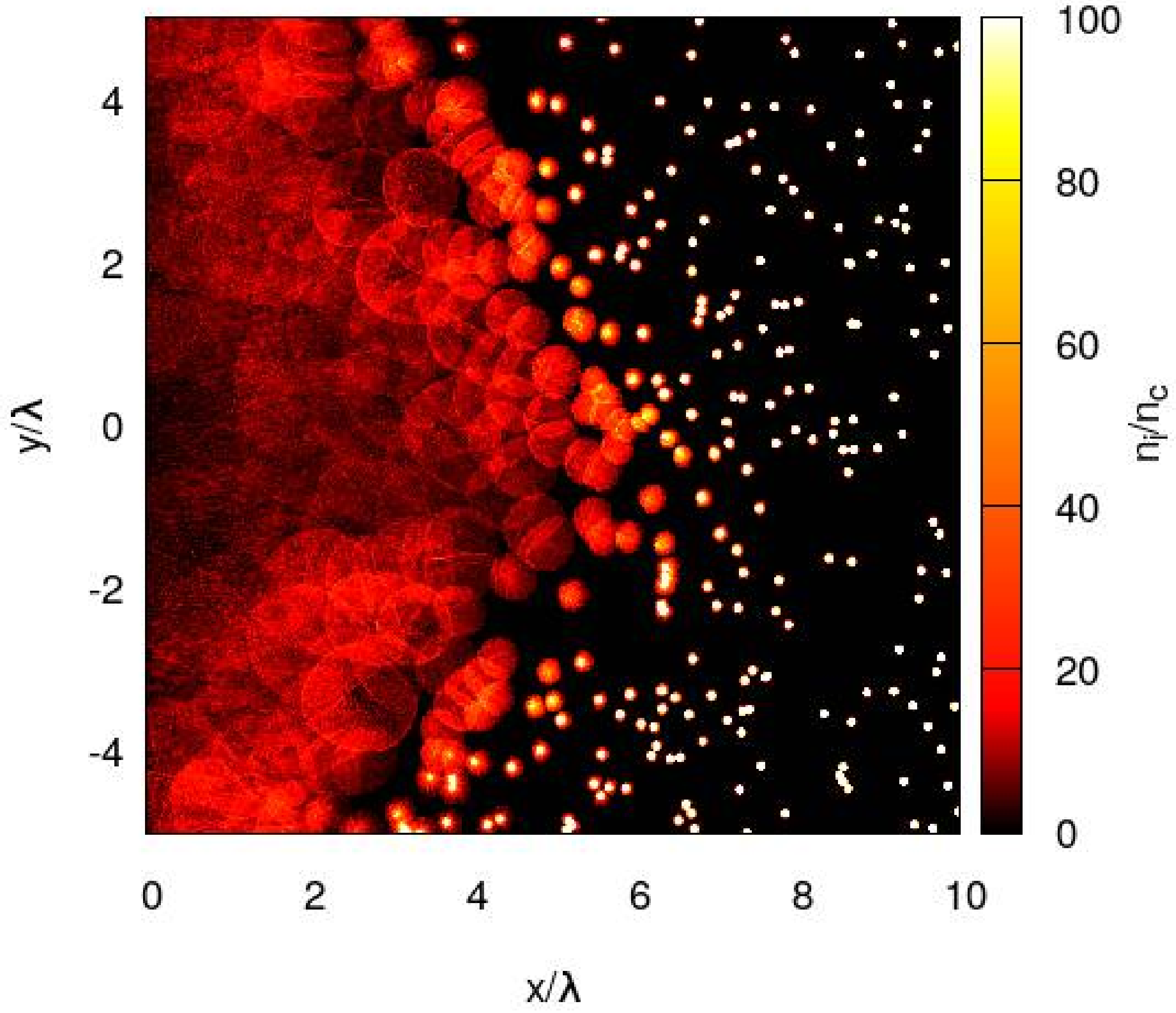
Nanostructured plasma

$$\bar{n} = \frac{n_e/n_c}{\sqrt{1+a_0^2/2}}$$

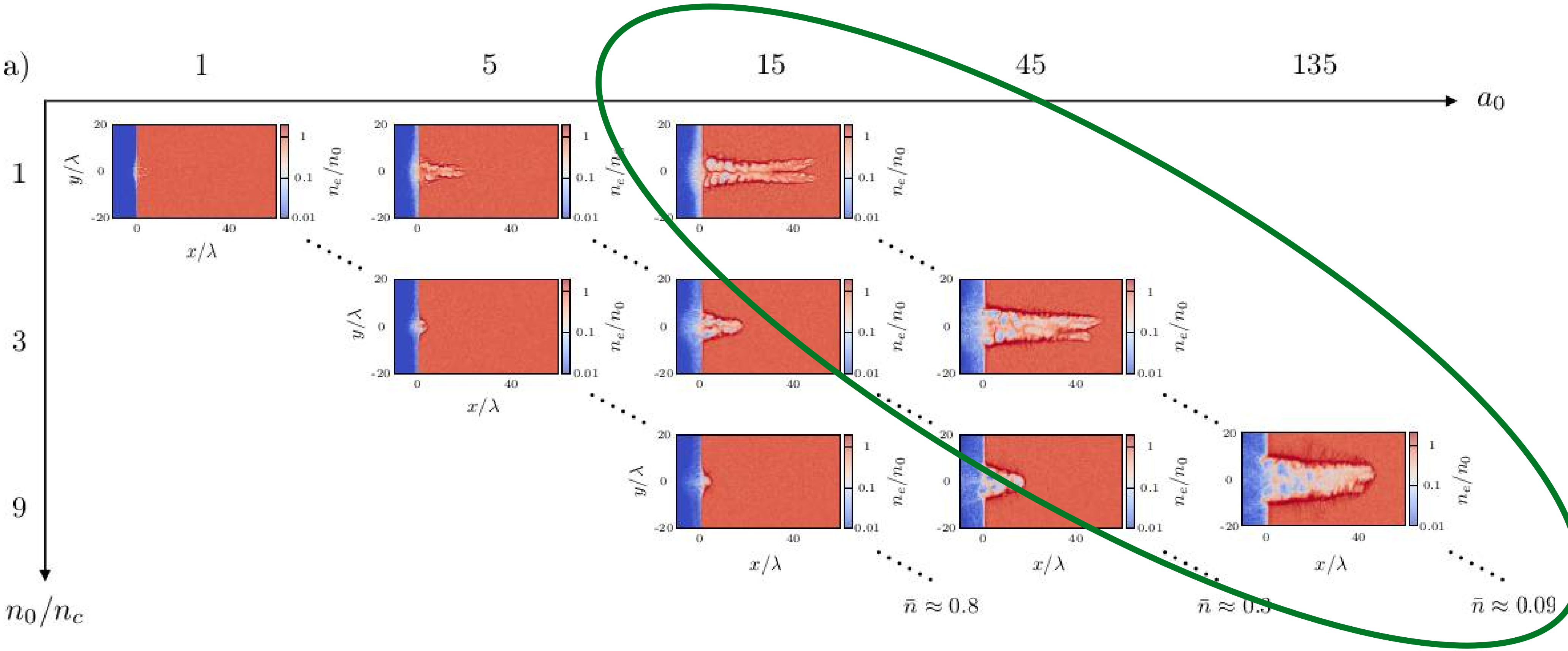
Main differences appear for partitioning of absorbed energy...



Main differences appear for partitioning of absorbed energy...

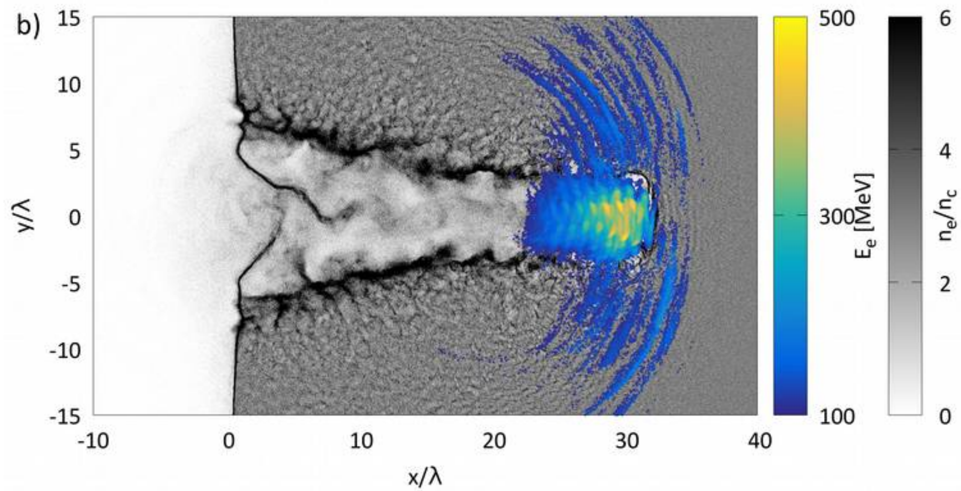


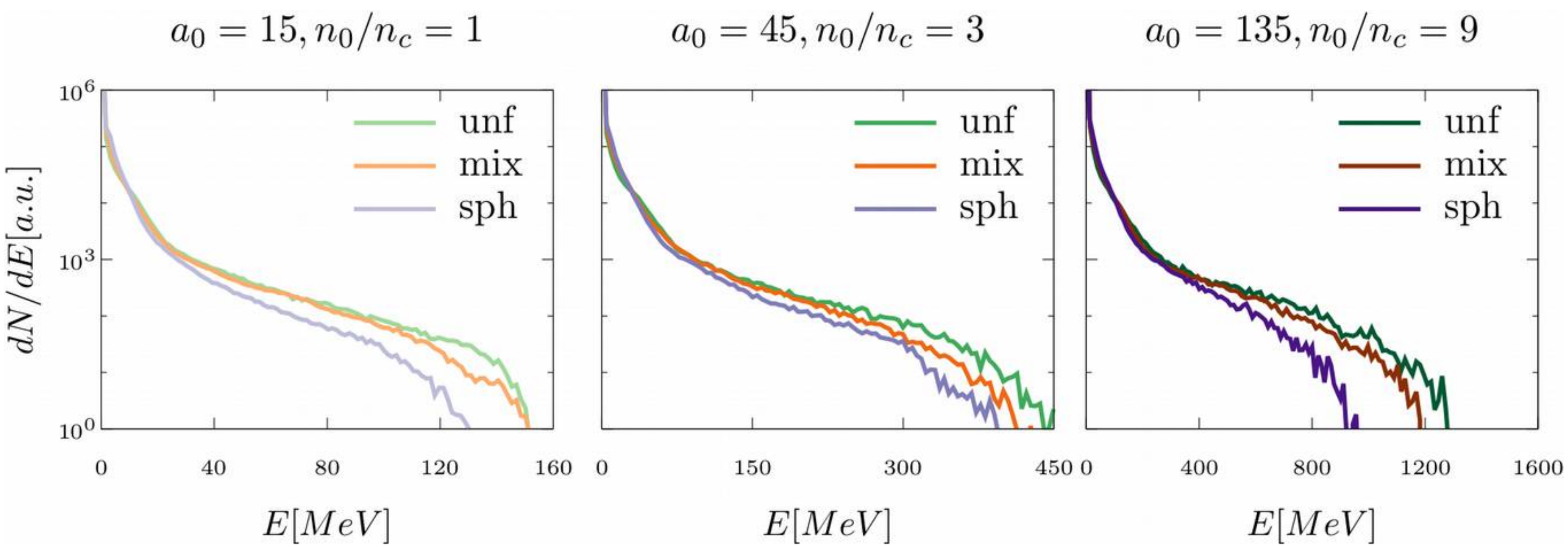
...and for the tail of electron energy spectra



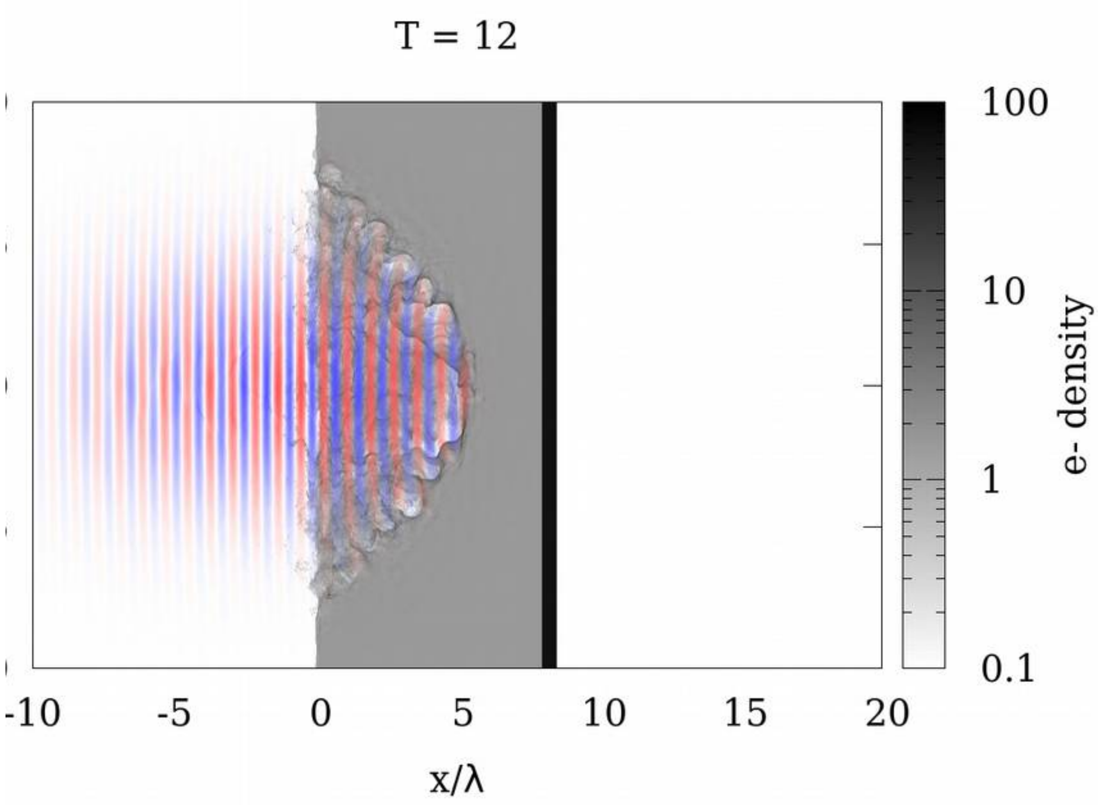
For electron energy spectra we restrict ourselves to this diagonal (highest transparency)

...and for the tail of electron energy spectra





A very similar approach was followed to simulated electron heating in near-critical foam-attached targets

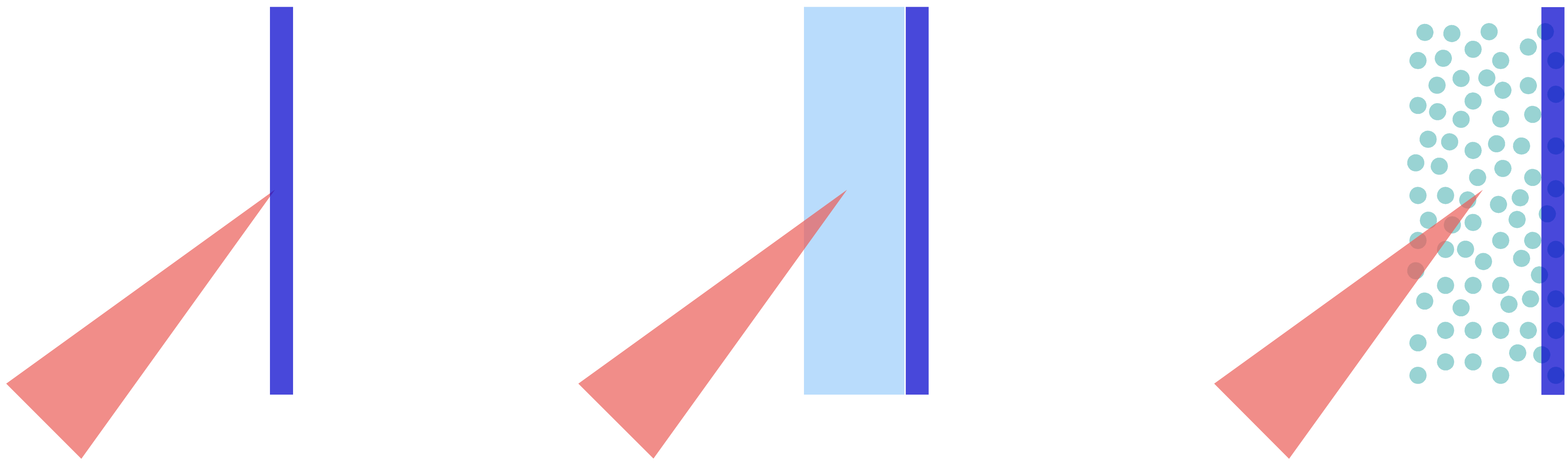


L.Cialfi, L.Fedeli & M.Passoni Phys.Rev.E 94 (2016)

Setup of the physical scenario

2D PIC simulations

Laser: p-polarized, a_0 = 1-15, 30° incidence,

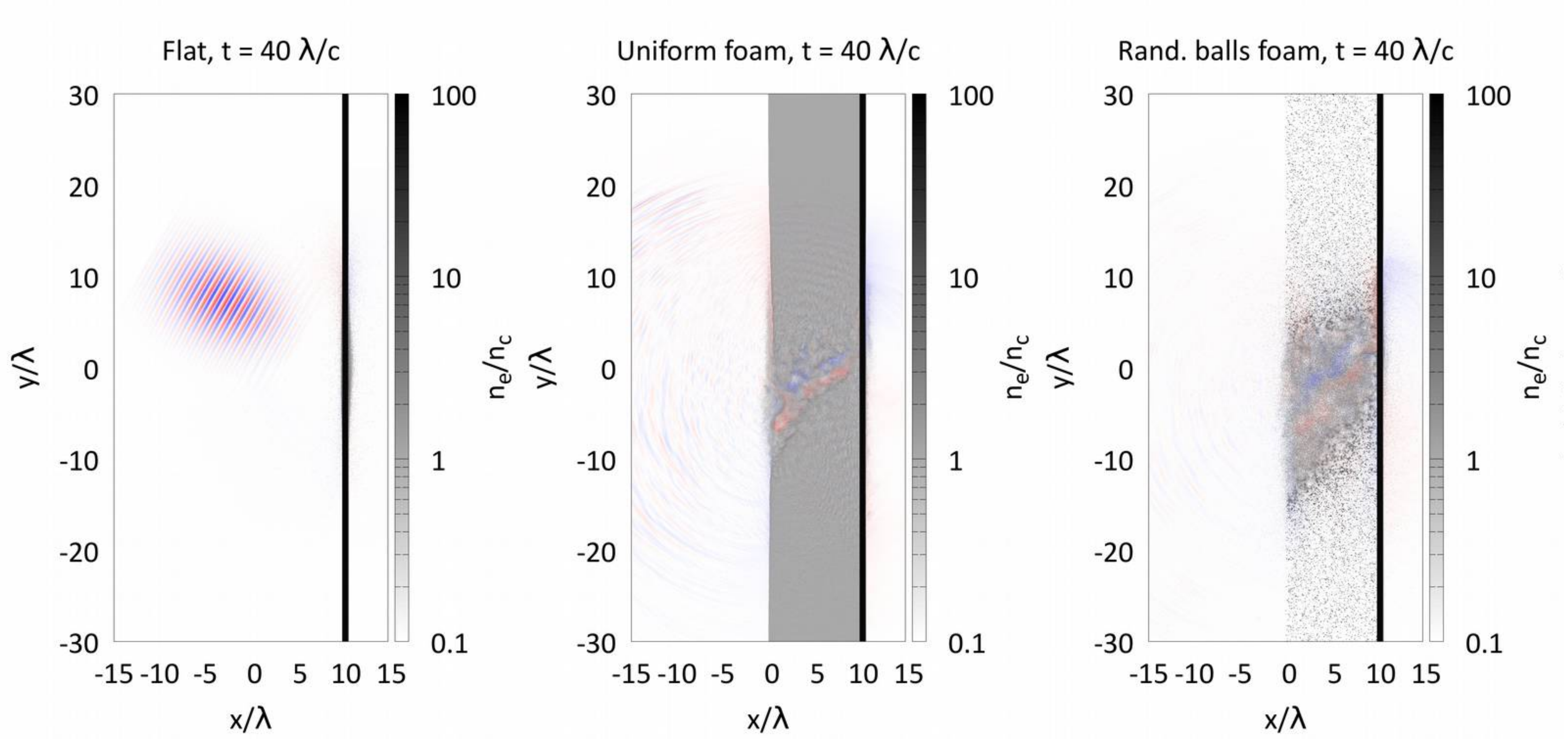


Simple flat target
80 n_c, 0.5 µm

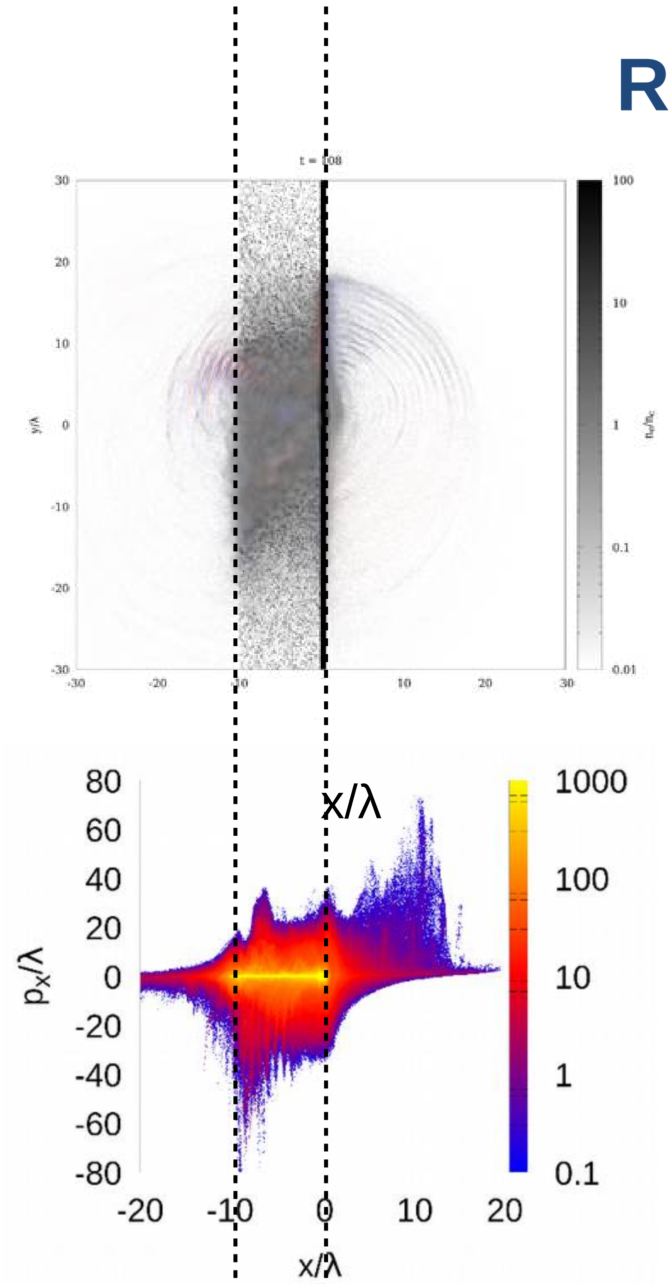
Unif. foam target
80 n_c, 0.5 µm +
1 n_c, 10 µm

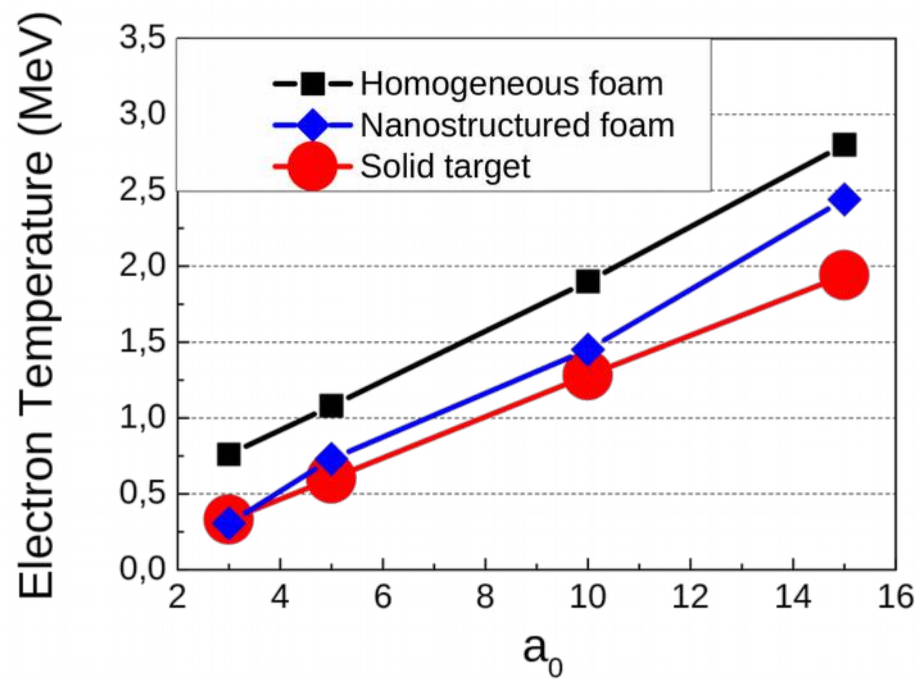
Nanost. foam target
80 n_c, 0.5 µm +
balls r=10 nm, n_e=100 n_c
avg.1 n_c, 10 µm

Setup of the physical scenario



Results: $T_{unif} > T_{nano} > T_{flat}$

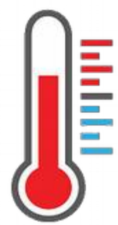




For foam-attached targets **we exclude the escaping fast-electron population**

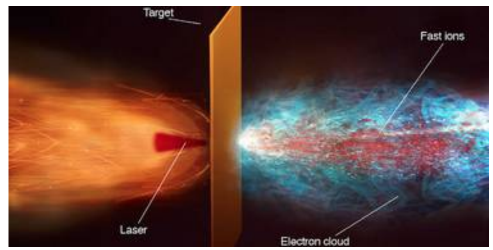
Benchmark with experimental results

e⁻ temperature from PIC sim.

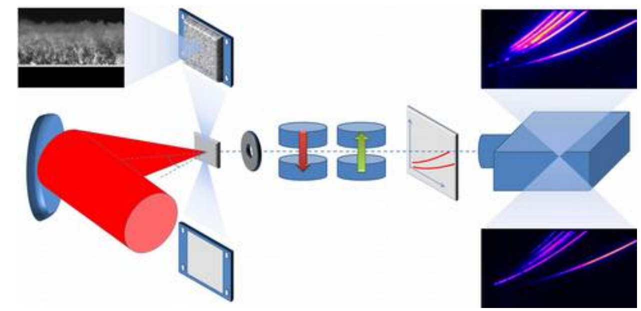


+

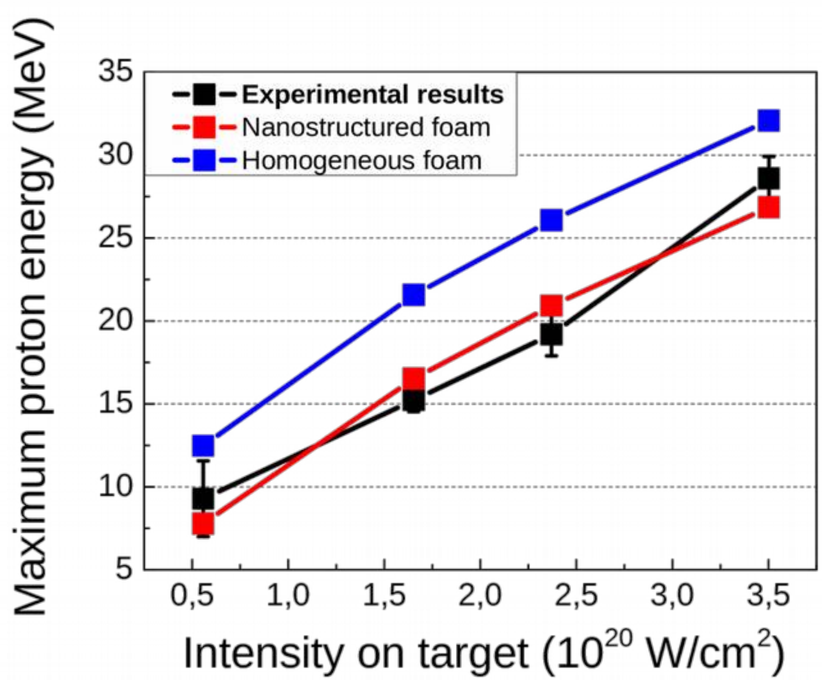
TNSA ion acceleration model*



Benchmark with exp.



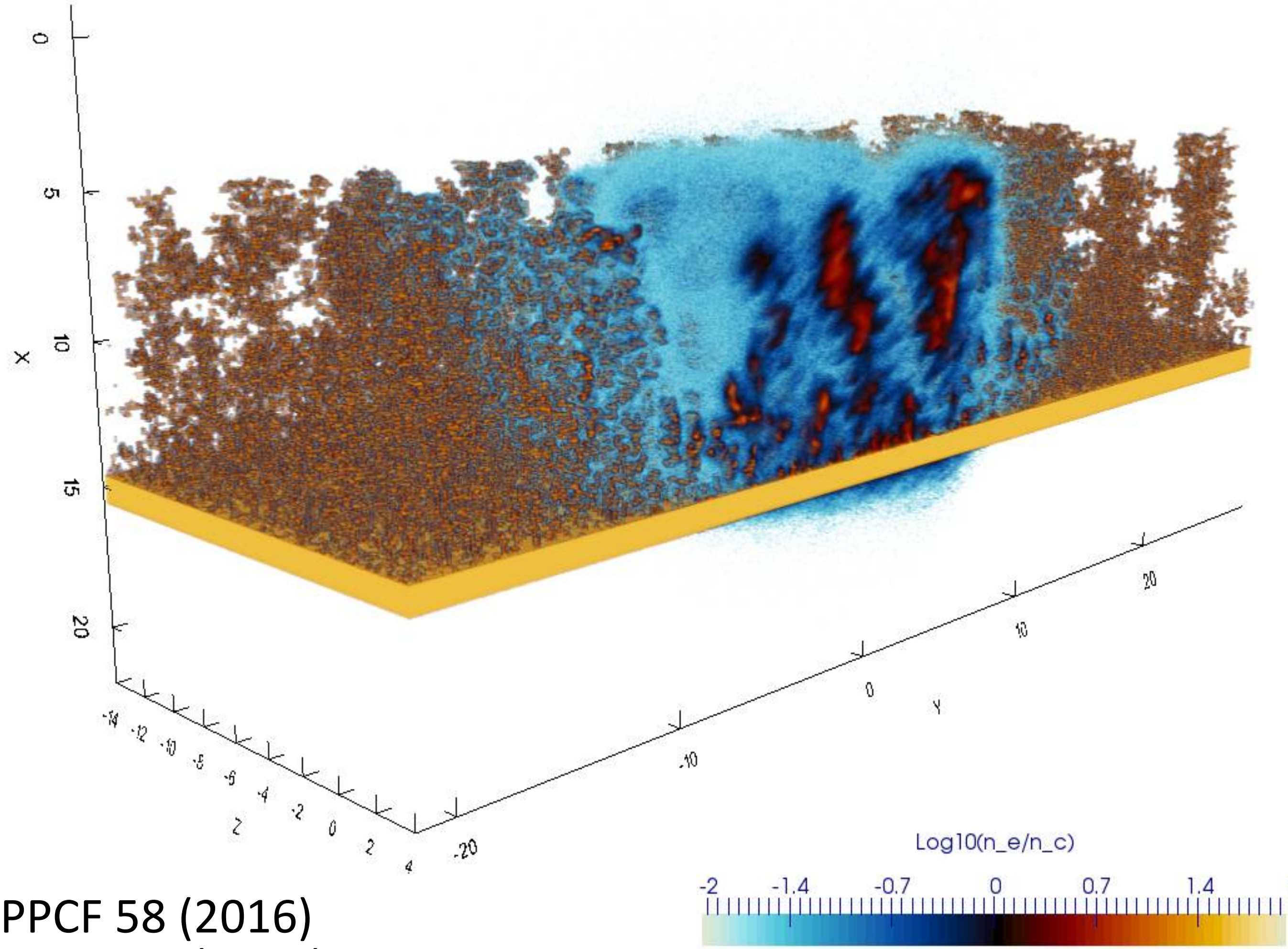
I.Prencipe et al. PPCF 58 (2016)
M.Passoni et al. PRAB 19 (2016)



*quasi-static
Passoni-Lontano model
Phys. Rev. Lett. 101 (2008)

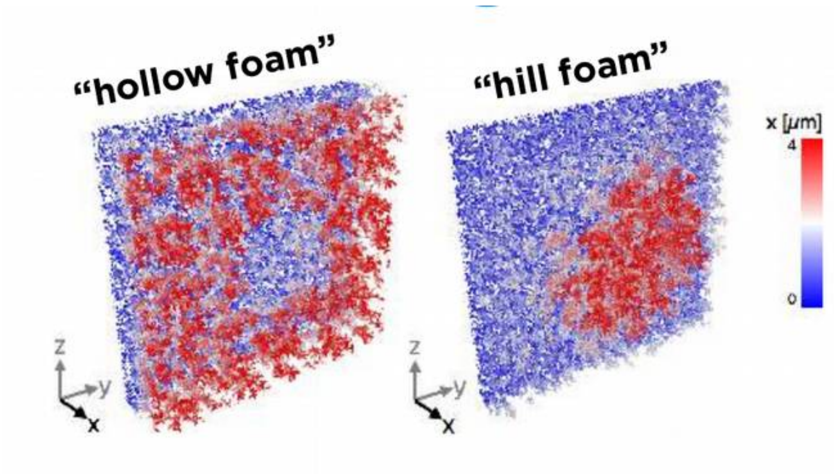
What’s next on this topic?

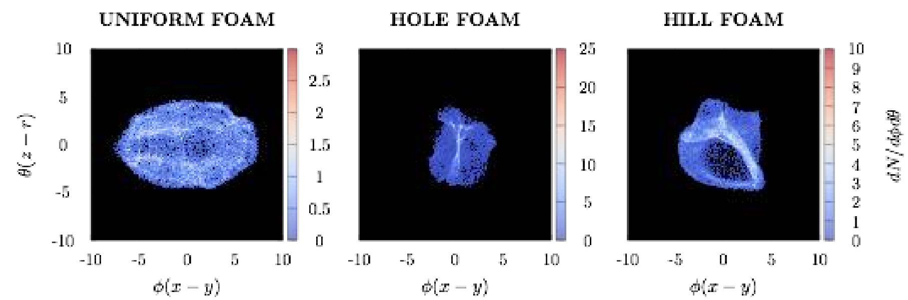
Synthetic diagnostics for realistic configurations



I.Prencipe et al. PPCF 58 (2016)
M.Passoni et al. PRAB 19 (2016)

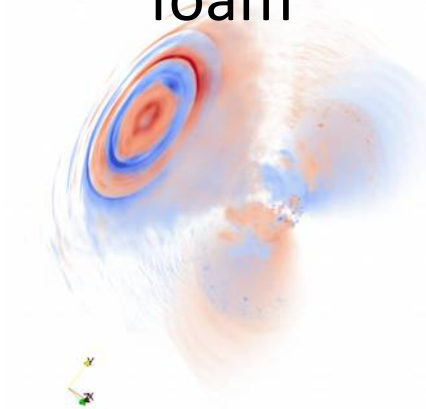
Synthetic diagnostics for realistic configurations



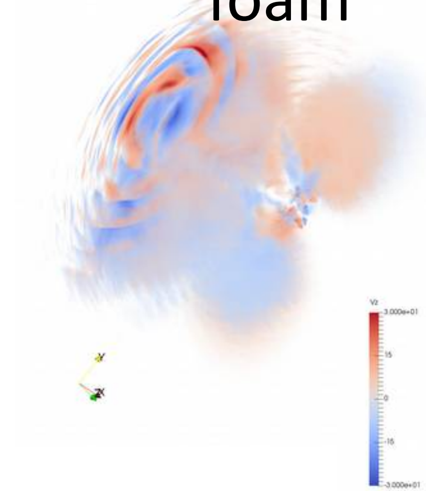


Flat target

Uniform foam

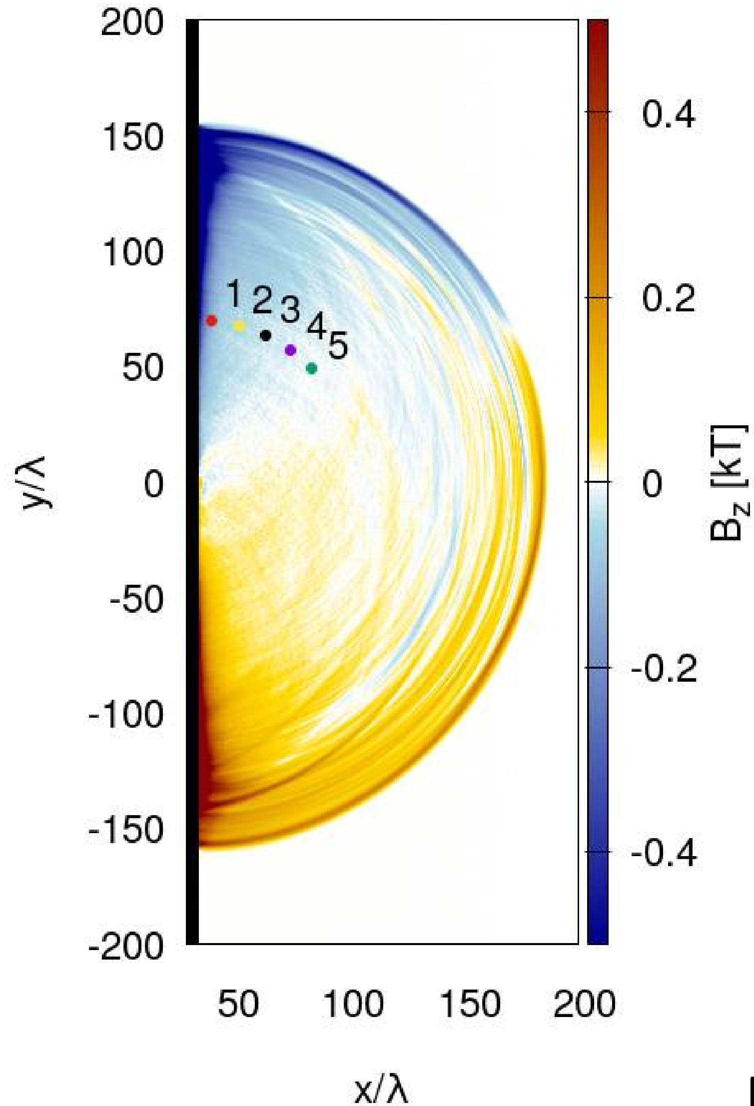


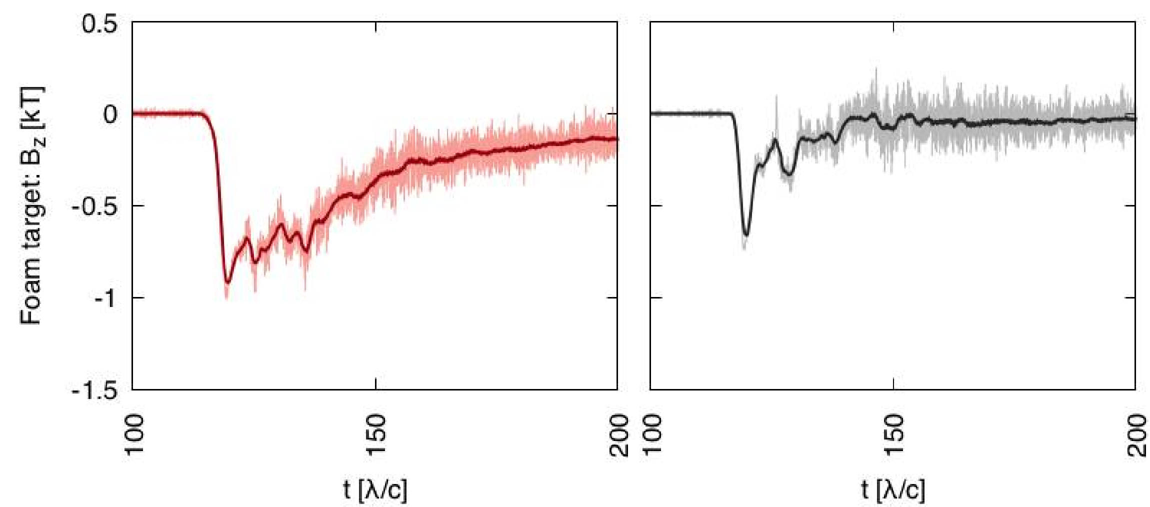
DLA foam



Reflected ligth& Synthetic RCF (realistic models)

THz emission from the back side?





Ding et al. Appl. Phys. Lett. 103 (2013)

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Conclusions

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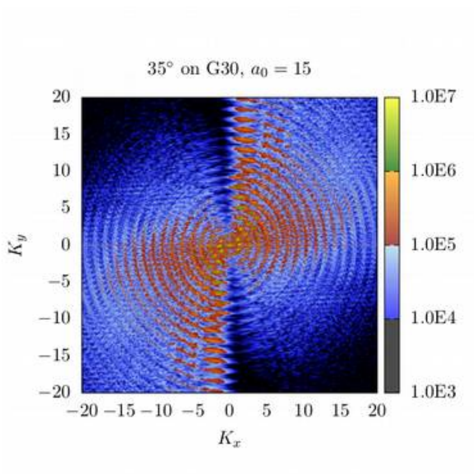
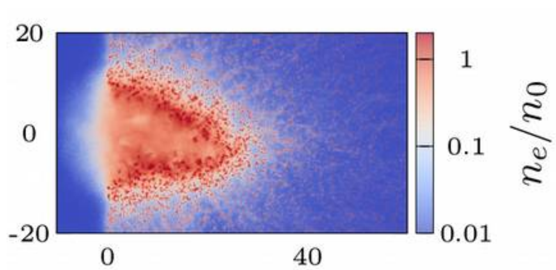
Conclusions



Irradiating a **grating** at the resonance angle for surface plasmon excitation should lead to the generation of higher-order harmonics with respect to simple flat targets



Nanostructured near-critical plasmas

Structure should be taken into account. Simulations suggest that experimental observables can be affected by the structure.

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Thank you for your attention