# Numerical particle-in-cell simulations of laser-plasma interaction at Politecnico di Milano

Arianna Formenti

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MILANO 1863

ERC-2014-CoG No. 647554
ENSURE

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Associate professor

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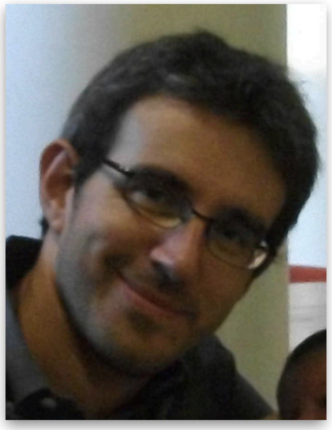
Researcher



**David Dellasega**
Post-doc

**Alessandro Maffini**
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**Luca Fedeli**
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**Arianna Formenti**
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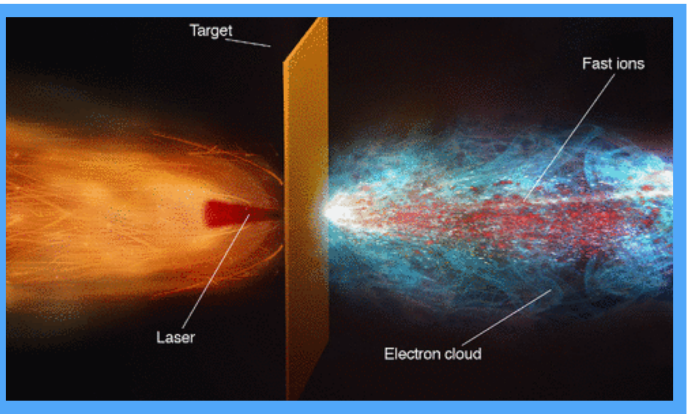
Master's student

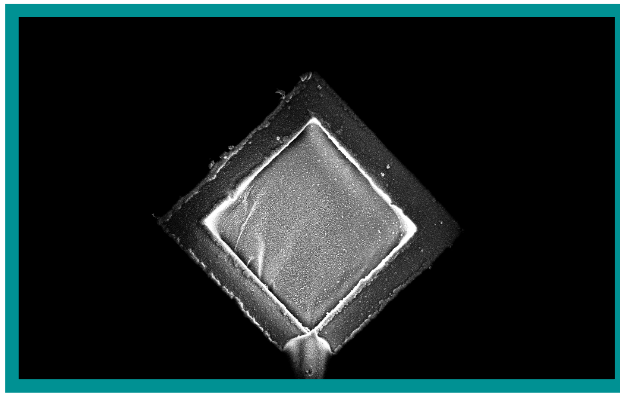
# ENSURE project
## Main research interests




**Laser-driven ion acceleration**
theoretical/numerical & experimental investigation

**Materials science**
development of low-density foams & advanced targets for laser-plasma experiments

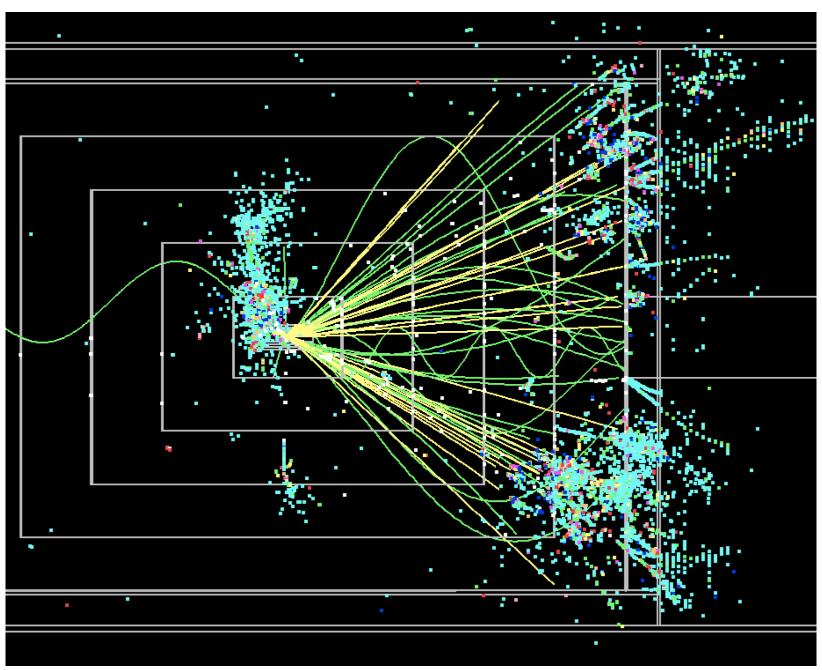
**Applications in materials and nuclear science**
materials characterization with laser-driven ions
& secondary neutron sources for radiography and detection



**Fundamental physics and laboratory astrophysics**
laser interaction with nanostructured plasmas
& collisionless shock acceleration of ions

# ENSURE project
## Numerical activity

**Particle-In-Cell simulations** with the open source, massively parallel code **piccante** to investigate laser-plasma interaction



**Monte Carlo simulations** with the open source code **Geant4** to investigate laser-driven sources interaction with matter

# ENSURE project
## Numerical activity

**Particle-In-Cell simulations** with the open source, massively parallel code **piccante** to investigate laser-plasma interaction

**Marconi @ CINECA, Bologna**
**HPC facility** - Intel OmniPath Cluster
access through ISCRA C & LISA & PoliMi grants (~ 100 kCPUhours each)

# Numerical activity
## Particle-In-Cell simulations

**some code developments**

charge-conserving current deposition scheme & OpenMP hybridization

A.Formenti, MSc thesis in Mathematical Engineering, Politecnico di Milano, 2016

**laser interaction with near-critical plasmas**

parametric 2D campaign to investigate laser propagation and absorption & role played by a model of nanostructure

L.Fedeli, A.Formenti, C.Bottani, M.Passoni EPJD (submitted)

**laser-driven ion acceleration**

2D & 3D simulations to study the role of a nanostructure on the accelerated ions properties

A.Formenti, MSc thesis in Mathematical Engineering, Politecnico di Milano, 2016

# **Numerical activity**
## Particle-In-Cell simulations

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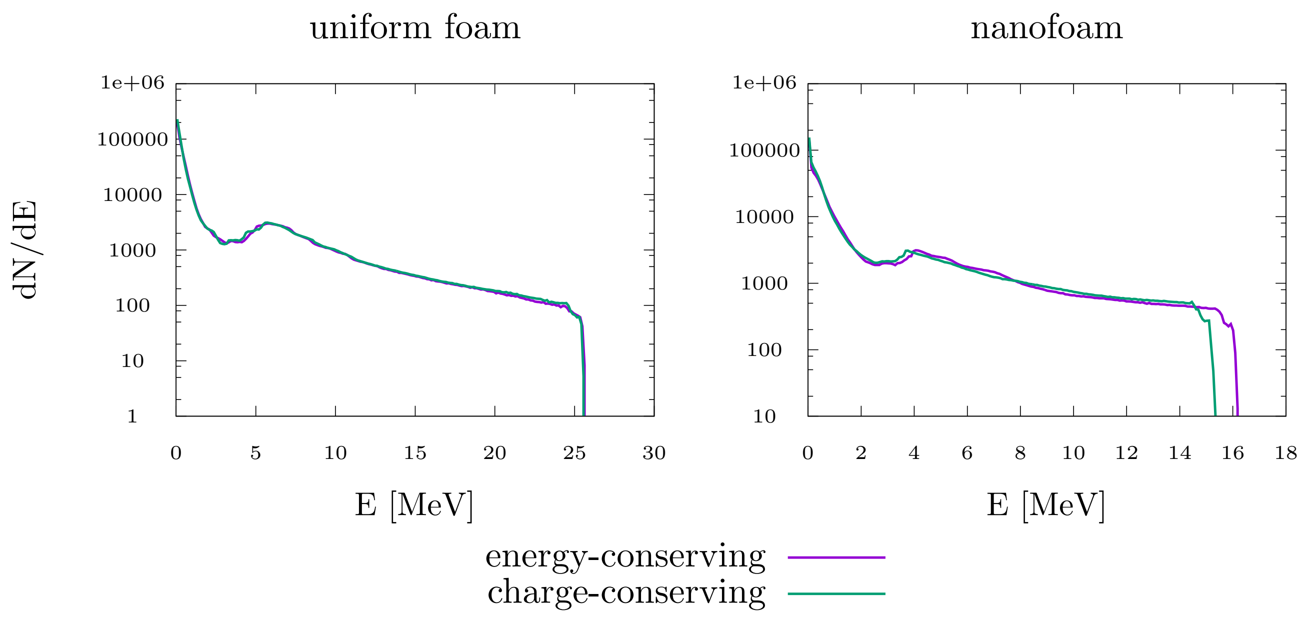
# Some code developments
## Addition to piccante 1

implementation of a **charge-conserving current deposition** scheme (Esirkepov method) for comparisons with energy-conserving scheme

**no significant differences** on main quantities of interest




almost **exact charge conservation**

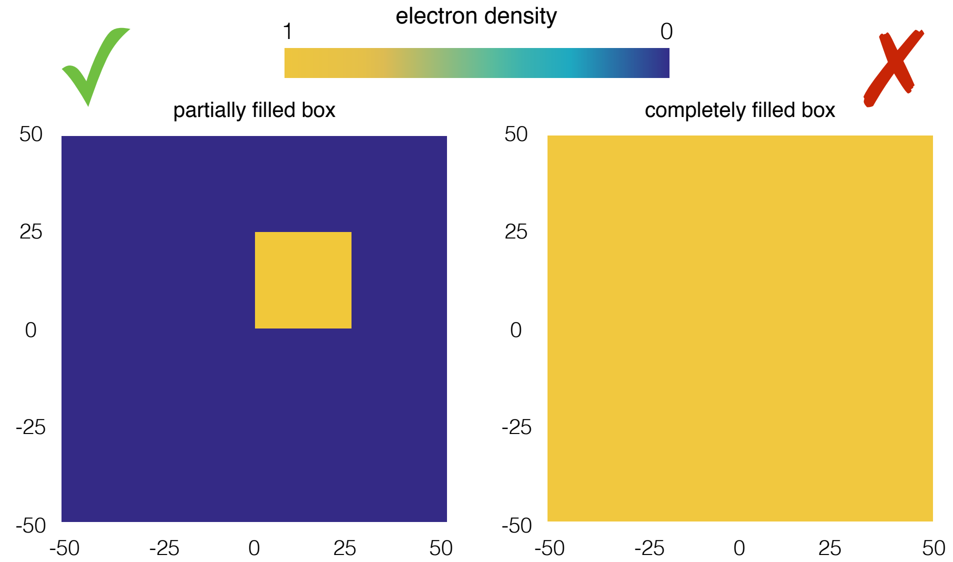
no exact **energy conservation** (but acceptable)

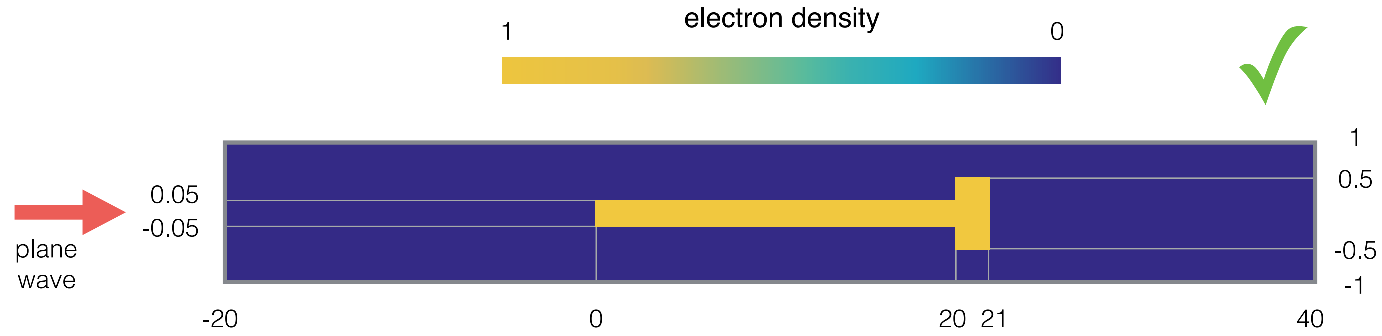
**very expensive** (~double CPUtime for a 2D simulation)

# Some code developments
## Addition to **piccante** 2

implementation of a **shared-memory parallelism paradigm**
to make **piccante** hybrid using OpenMP
+
**should be useful** on new Marconi @ CINECA partitions
based **on new** Intel KNL **architectures**

on “old” architectures (Galileo @ CINECA)
works better than MPI only for
**VERY, VERY inhomogeneous plasmas**



# Numerical activity
## Particle-In-Cell simulations

**some code developments**

charge-conserving current deposition scheme & OpenMP hybridization

**laser interaction with near-critical plasmas**

parametric 2D campaign to investigate laser propagation and absorption & role played by a model of nanostructure

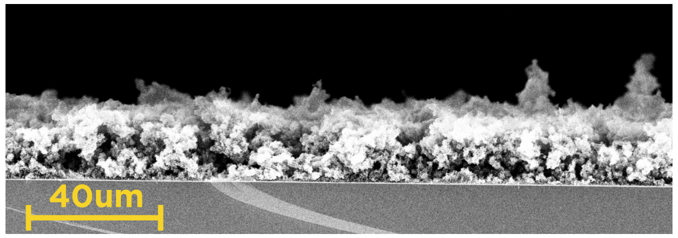
**laser-driven ion acceleration**

2D & 3D simulations to study the role of a nanostructure on the accelerated ions properties

# Laser interaction with near-critical plasmas
## Motivations

near-critical regime **not widely explored** also because experimentally (especially for targetry) and theoretically **challenging**

few methods to obtain a near-critical density material: aerogels, nanotube arrays, **foams**




$\nexists$ extensive parametric scans (intensity, density, structure)

interesting for various **applications**:

- laser-driven particle sources
- laboratory astrophysics
- advanced ICF schemes
- ultra-intense, ultra-short $\gamma$ sources



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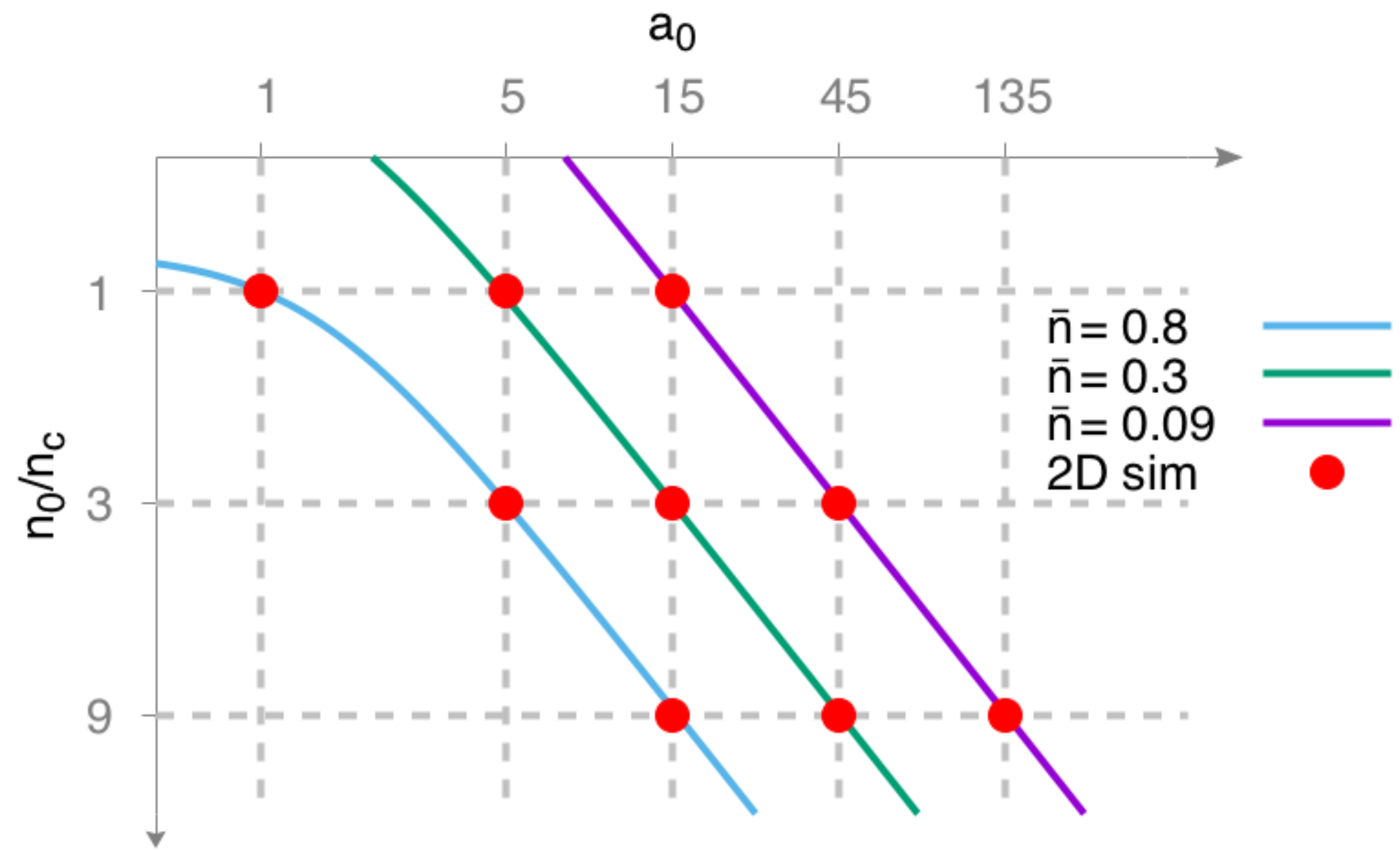
# Laser interaction with near-critical plasmas
## Particle-In-Cell simulations

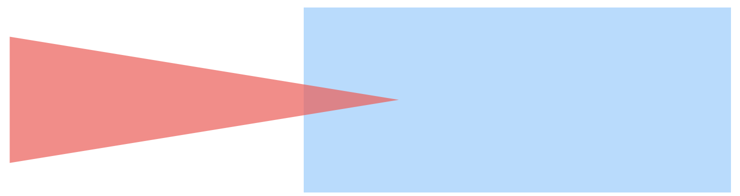
exploration of the parameter space **($a_0$, $n_0/n_c$)**
keeping the relativistic transparency constant for some simulations

"relativistic transparency coefficient"
for a P-polarized laser pulse

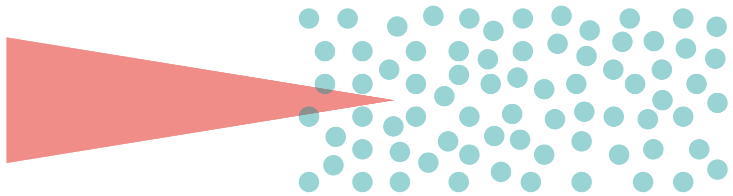
$$\bar{n} = \frac{n_0/n_c}{\sqrt{1+\frac{a_0^2}{2}}}$$




**uniform** plasmas



**nanostructured** plasmas

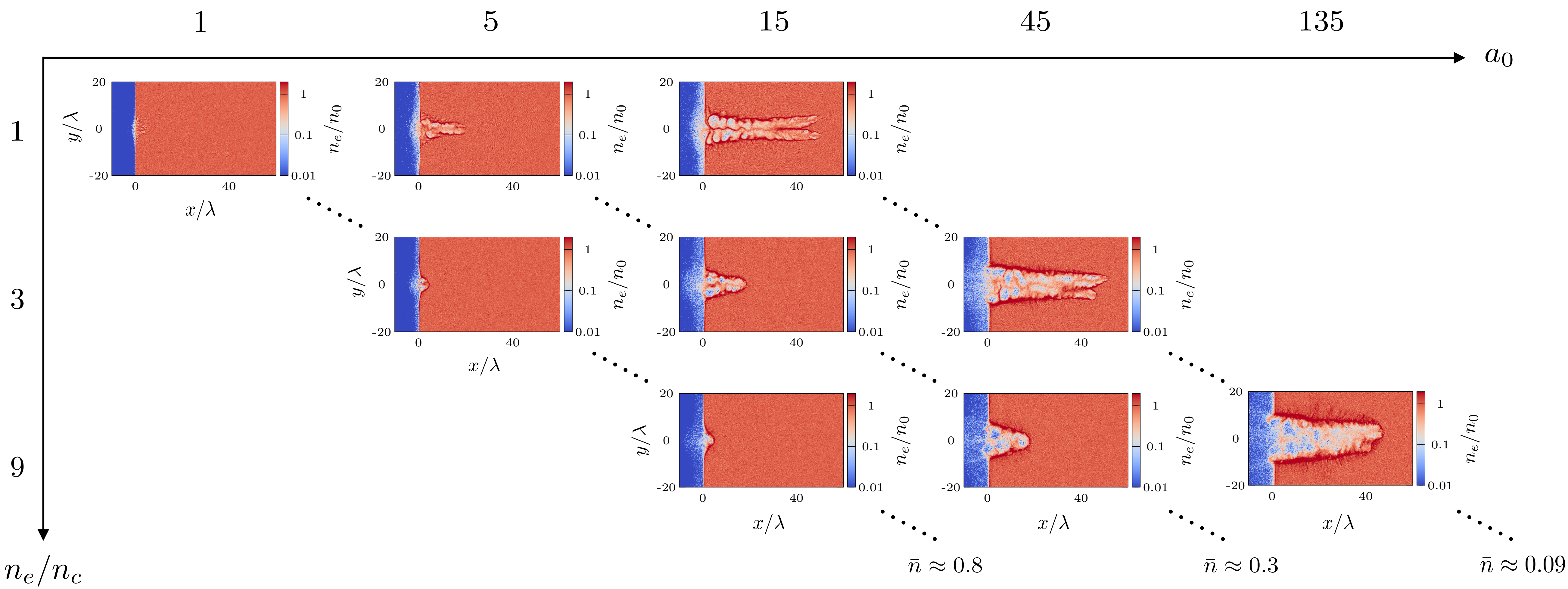


modeled as collections of random nanospheres

# Laser interaction with near-critical plasmas
## Results

**self-similar behavior** for constant transparency

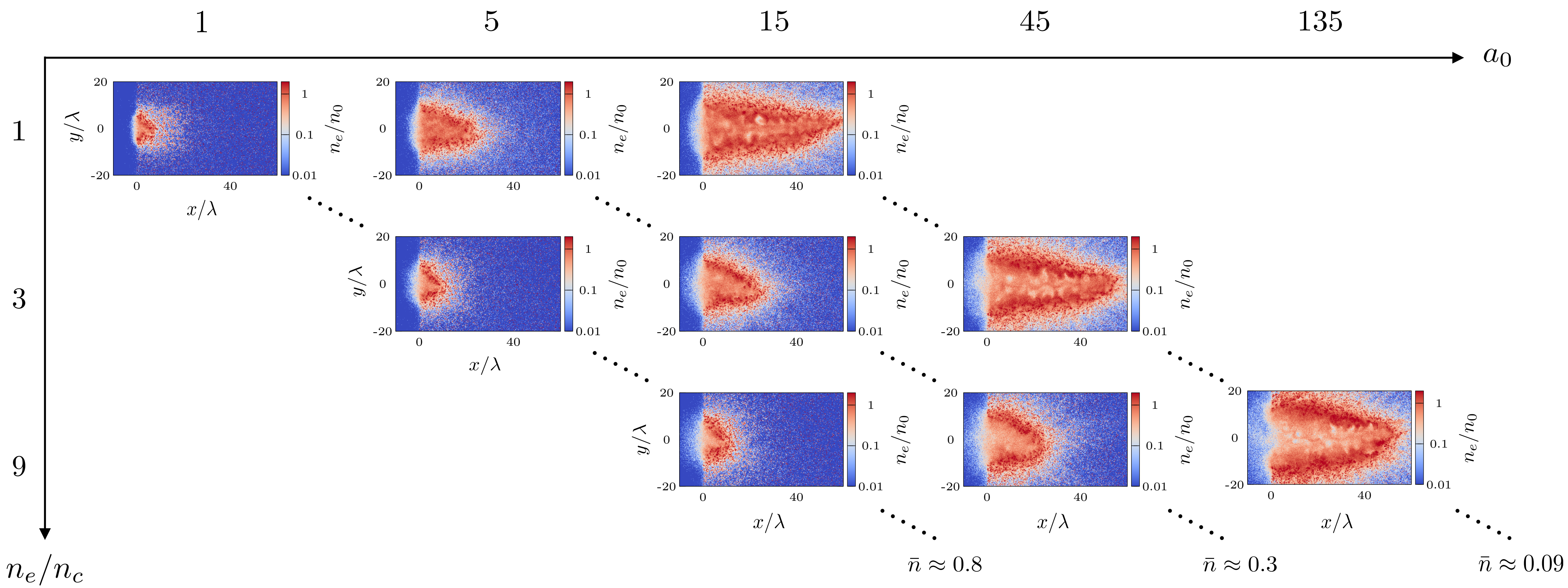
electron density plots — **uniform plasma** case



# Laser interaction with near-critical plasmas
## Results

**self-similar behavior** for constant transparency
even if the plasma is nanostructured

electron density plots — **nanostructured plasma** case



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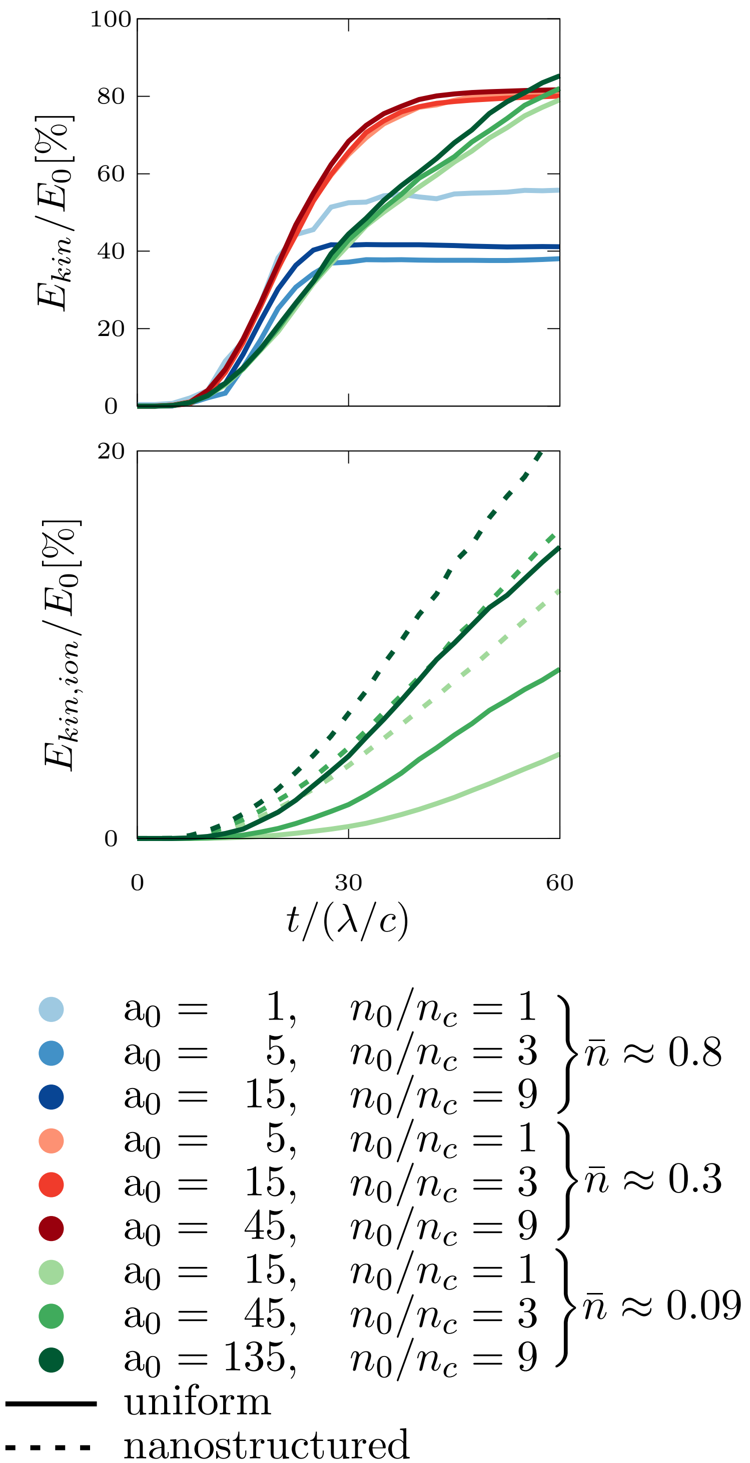
# Laser interaction with near-critical plasmas

## Results

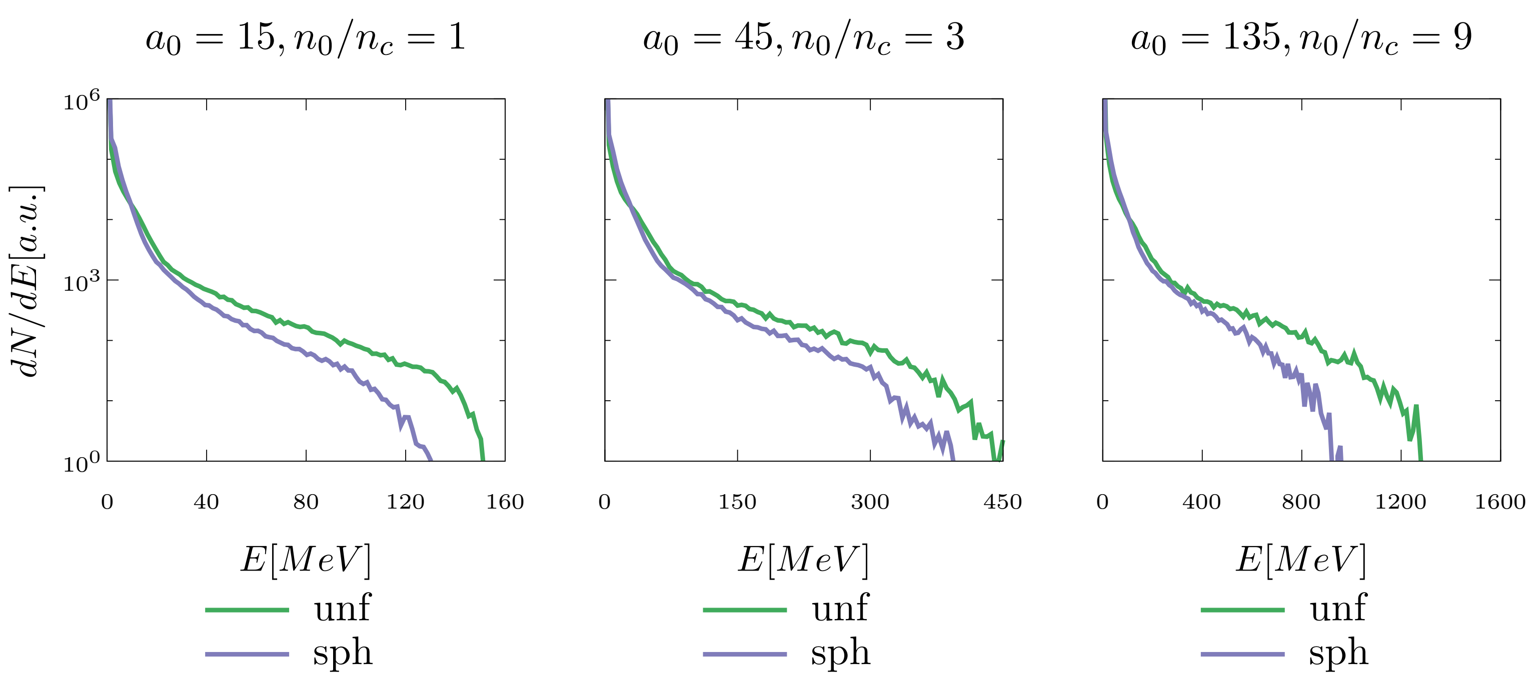
**self-similar behavior** also in the energy absorption

&

the nanostructure allows for a **higher** conversion efficiency of laser energy into **ion kinetic energy**




**depletion** of the high energy **tail of the electron spectra** if the nanostructure is present (may have consequences on ion acceleration)



# Numerical activity
## Particle-In-Cell simulations

**some code developments**

charge-conserving current deposition scheme & OpenMP hybridization

**laser interaction with near-critical plasmas**

parametric 2D campaign to investigate laser propagation & role played by a model of nanostructure

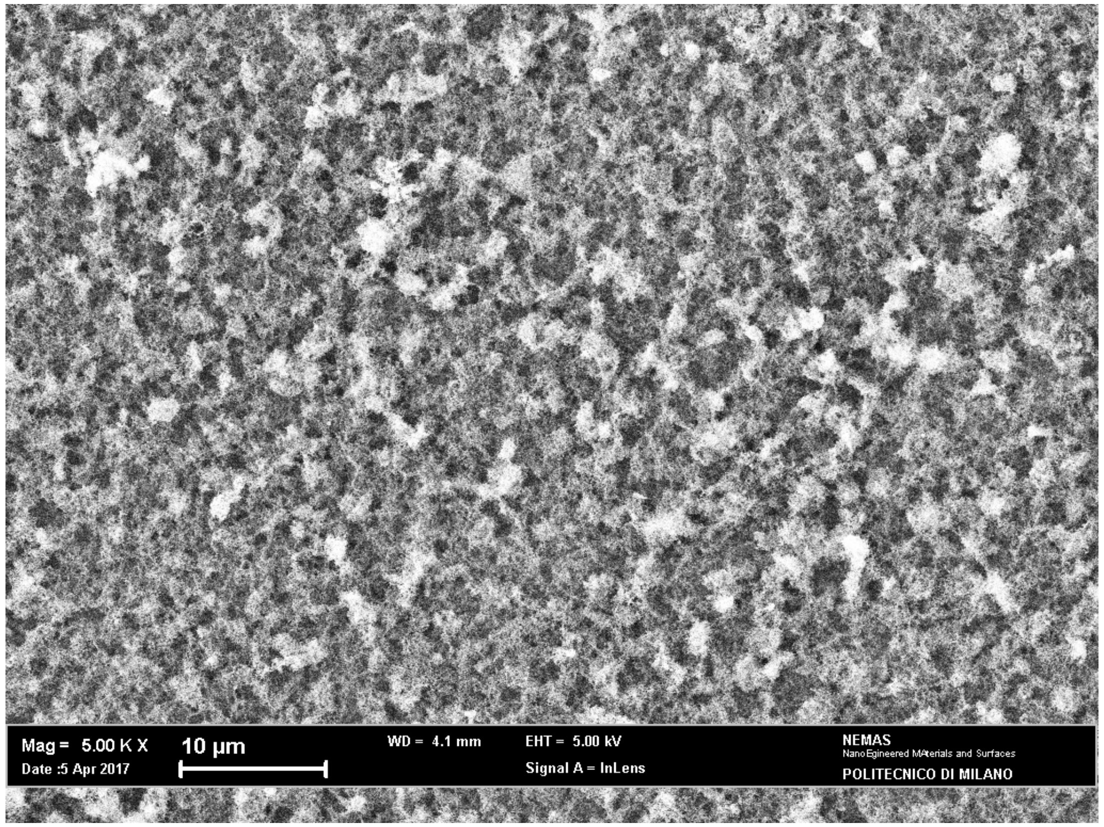
**laser-driven ion acceleration**

2D & 3D simulations to study the role of a nanostructure on the accelerated ions properties

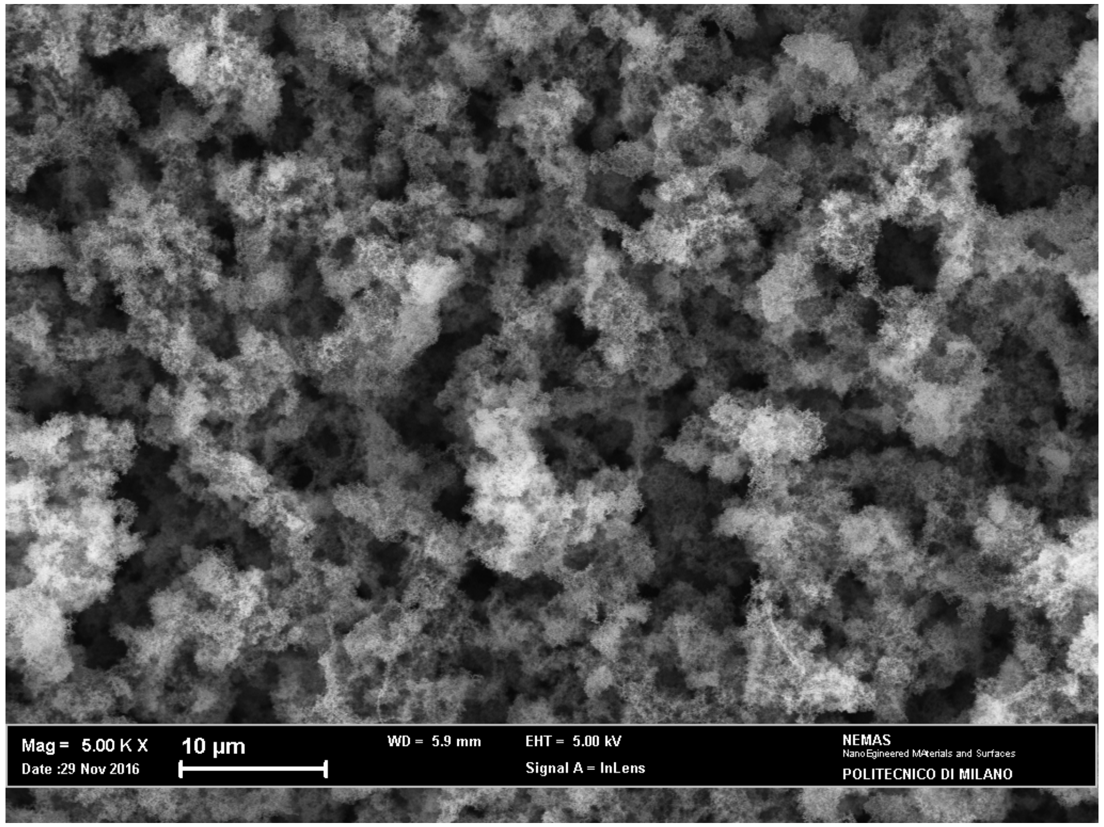
# Laser-driven ion acceleration
## Motivations

real foams used in ion acceleration experiments
show very **complex** and **different morphologies** and **structures**,
i.e. many non-idealities: very far from being homogeneous

→ average density is not the only relevant foam parameter



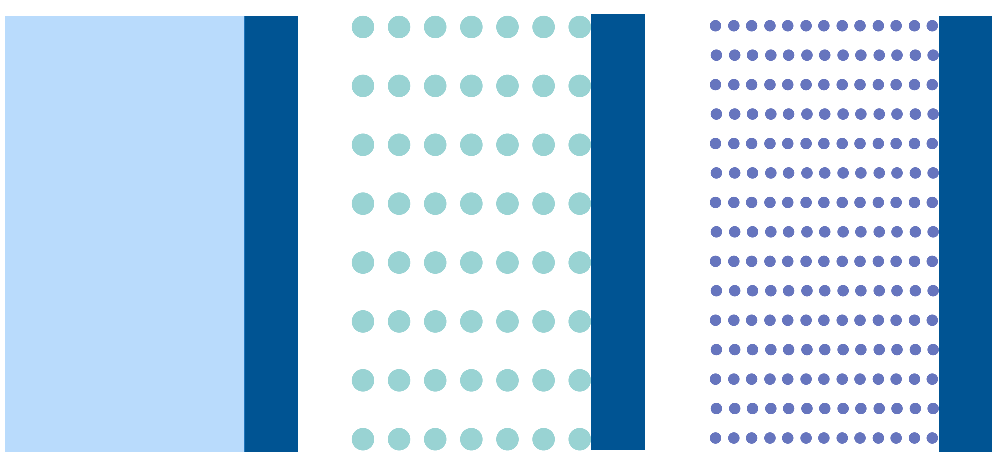

SEM image - top view




SEM image - top view

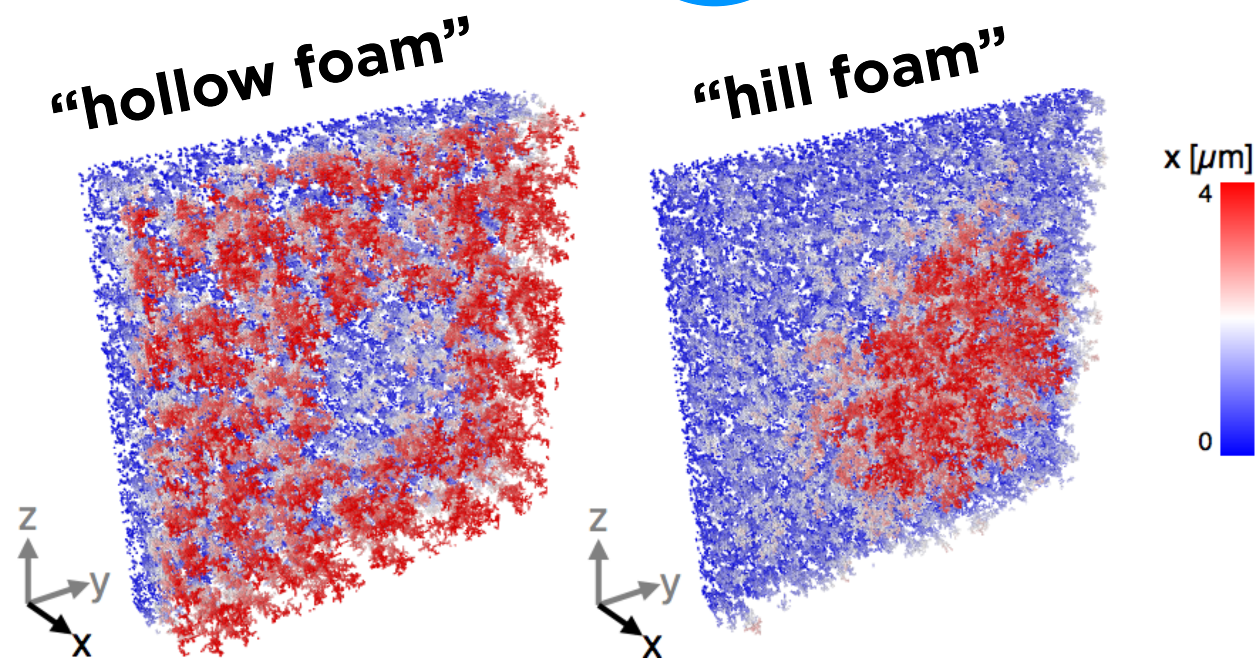
# Laser-driven ion acceleration
## Particle-In-Cell simulations

**2D**



- **ordered nanospheres**
- **same density, different morphology**
- average density = $1n_c$
- thickness = $5\lambda$
- radius = $0.01\lambda \div 0.05\lambda$,
- distance = $0.25\lambda \div 1\lambda$

**3D**




- **diffusion-limited-aggregation foam**
- average density = $2n_c$
- non-constant thickness profile
- maximum thickness = $5\lambda$
- radius = $0.05\lambda$
- laser waist = $3\lambda$
- central region radius = $5\lambda$

# Laser-driven ion acceleration
## Results

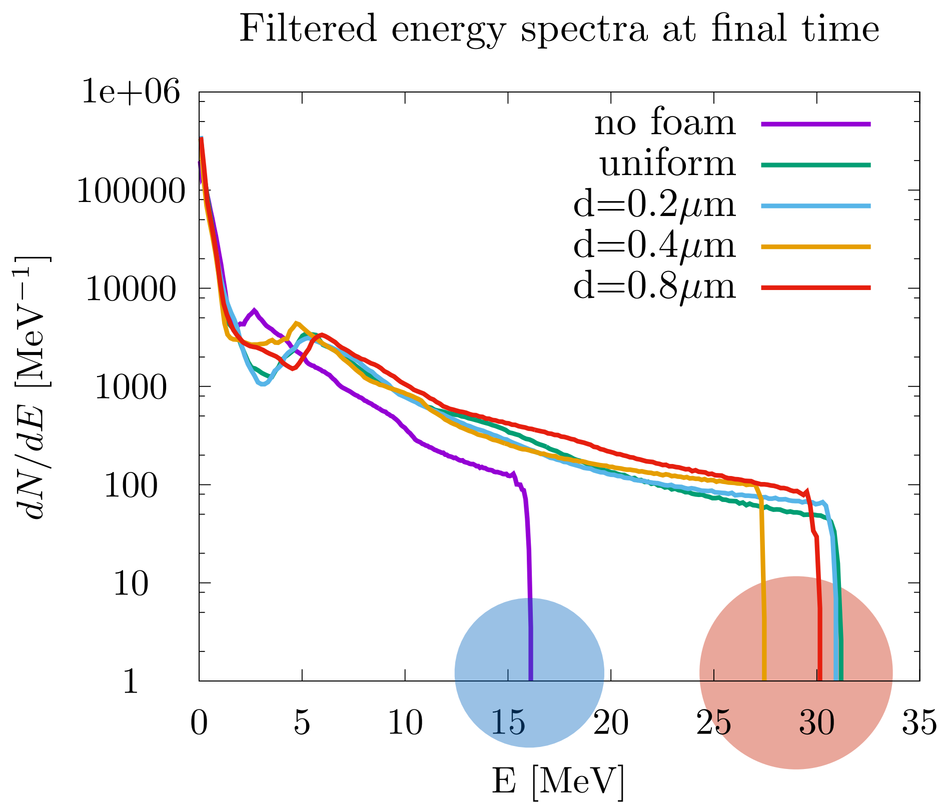
**proton energy spectra**

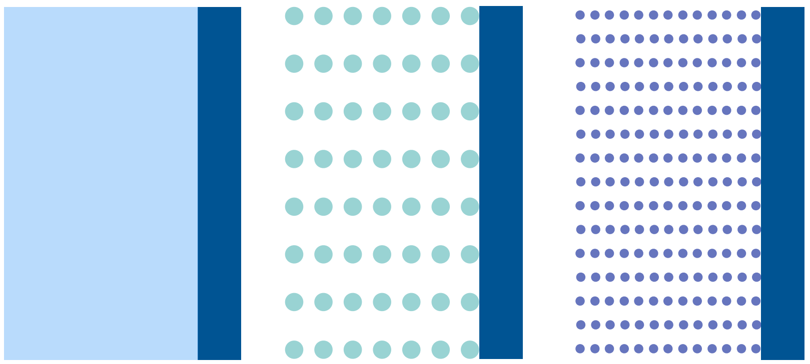
**2D**

highest maximum proton energy
for the smallest and closest
nanospheres

**no foam**

**different nanostructures**



# Laser-driven ion acceleration
## Results

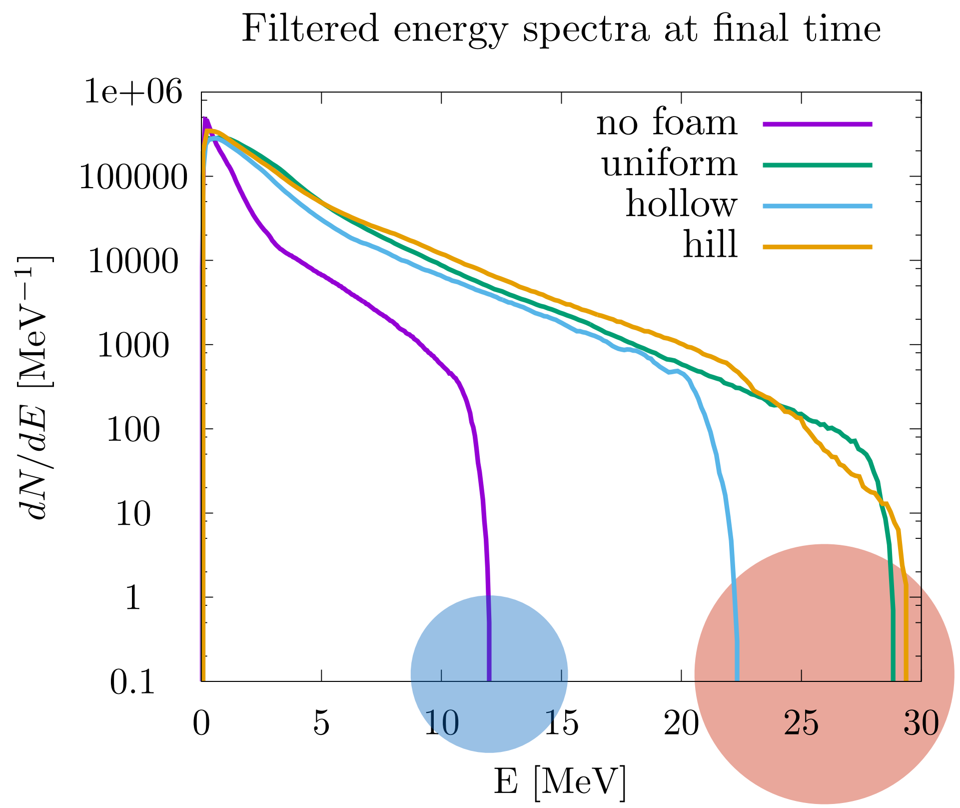
**proton energy spectra**

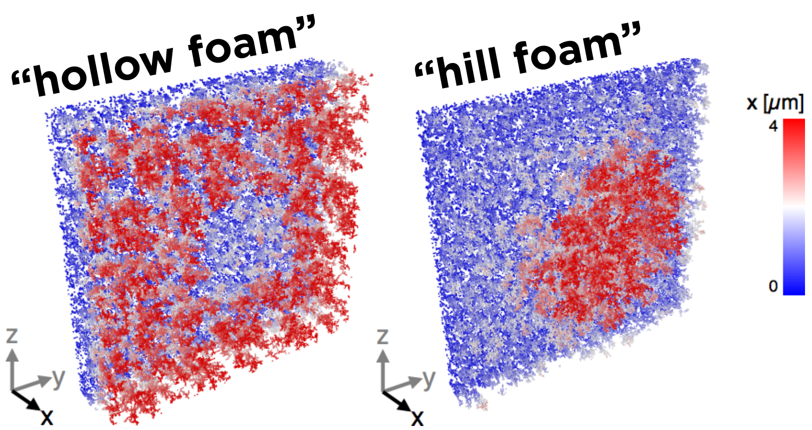
**3D**

thickness profile plays and important role on proton cutoff energy

**no foam**

**different nanostructures**

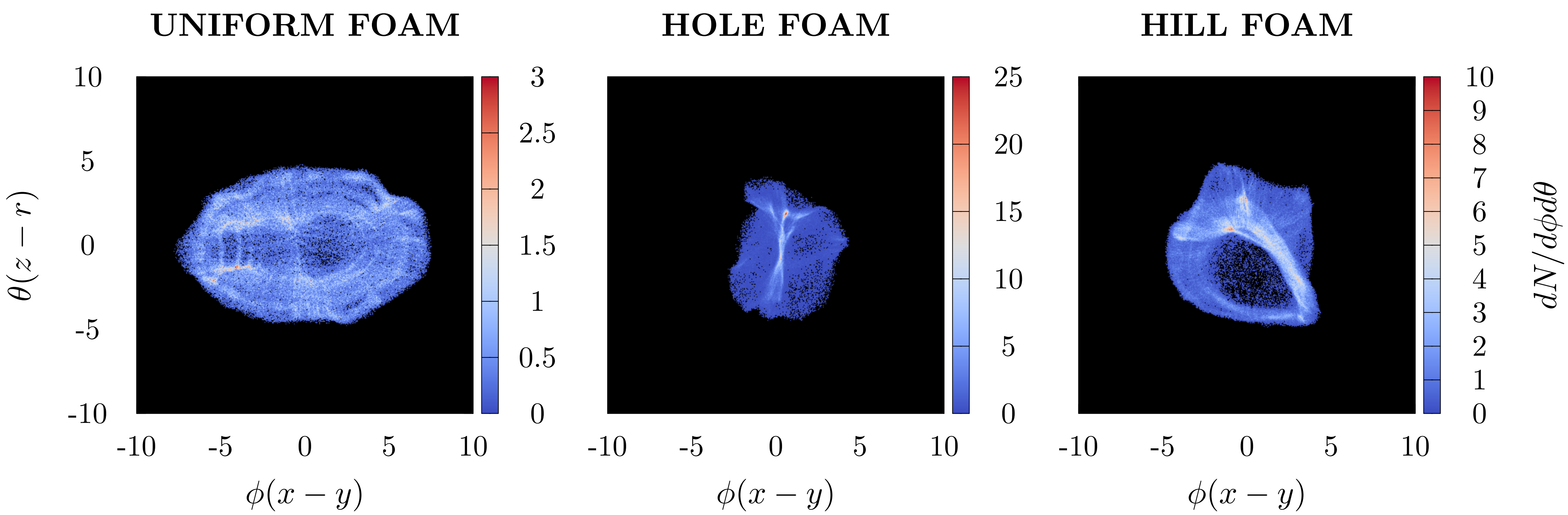


# Laser-driven ion acceleration
## Results

3D

**synthetic radiochromic films** (i.e. angular ion spectra)
show very different features for high energy protons (E ~ 20 MeV)
depending on the specific thickness profile



# Summary

**a group the works on PIC simulations of laser-plasma interaction ∃ @PoliMi**

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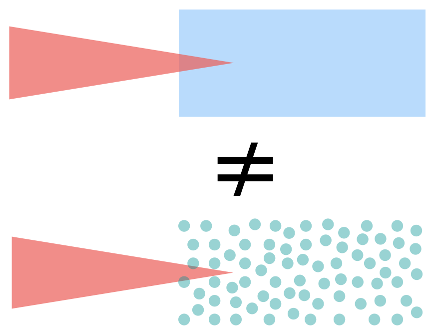
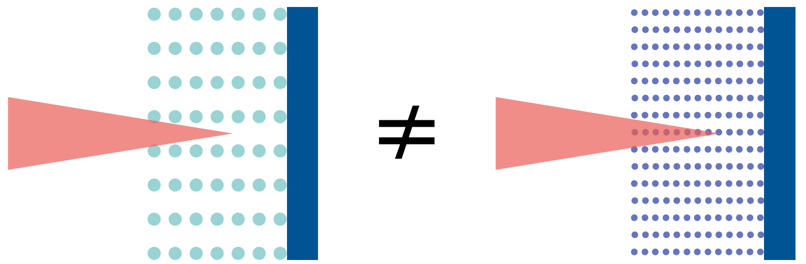
**some code developments**
2 additional features in piccante

**laser interaction with near-critical plasmas**
the ∃ of a nanostructure plays a role



**laser-driven ion acceleration**
different nanostructures lead to different results



# More info on our website

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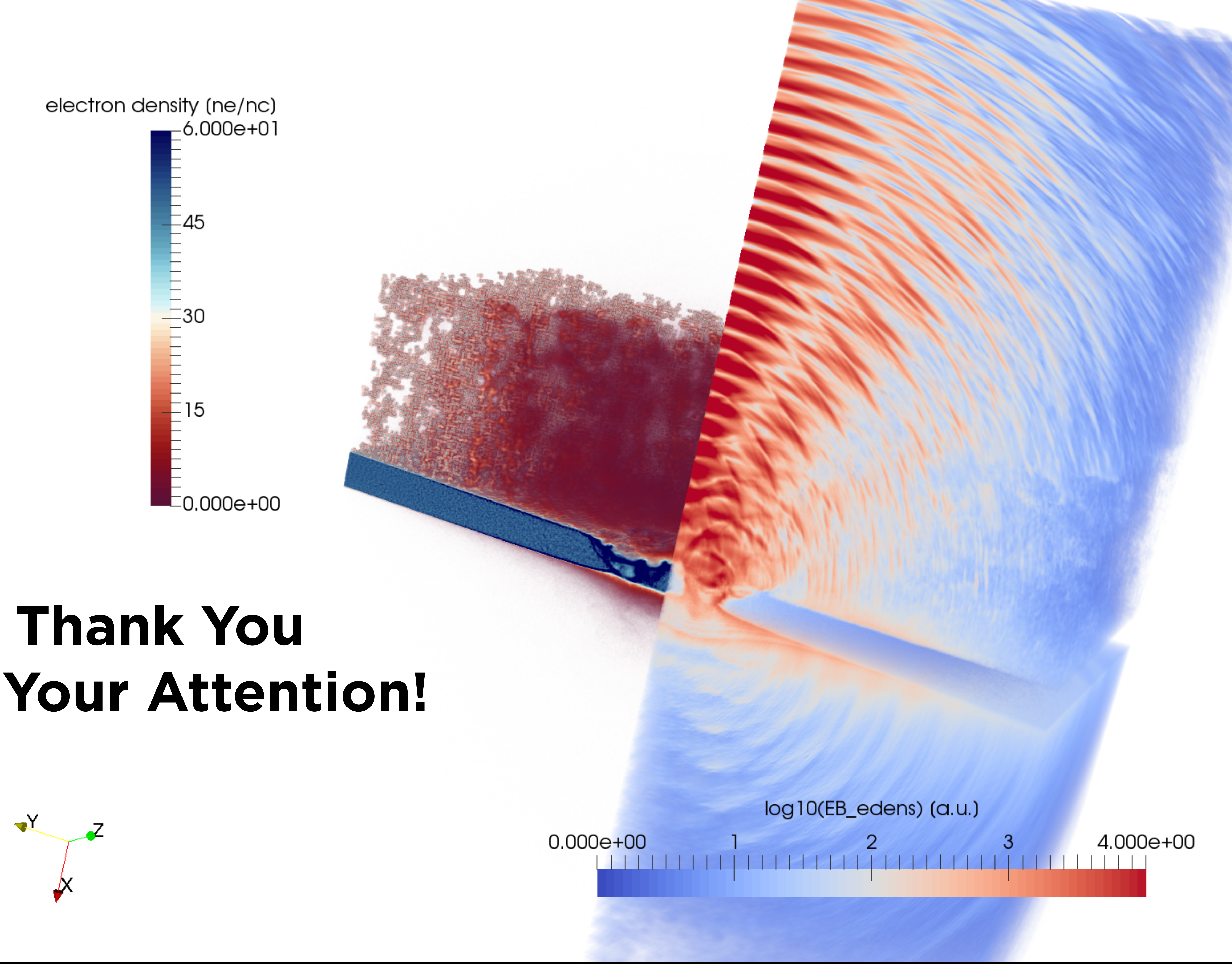


# Thank You
# For Your Attention!

# Our publications on journal papers

L. Fedeli, A. Formenti, C. E. Bottani, M. Passoni
*Parametric investigation of laser interaction with uniform and nanostructured near-critical plasmas,*
Submitted to EPJD

A. Maffini, L. Moser, L. Marot, R. Steiner, D. Dellasega, A. Uccello, E. Meyer and M. Passoni,
*In situ cleaning of diagnostic first mirrors: an experimental comparison between plasma and laser cleaning in ITER-relevant conditions,*
Nucl. Fusion 57 (2017) 046014 (13pp)

L. Fedeli, A. Sgattoni, G. Cantono and A. Macchi,
*Relativistic surface-plasmon enhanced harmonic generation from gratings,*
Appl. Phys. Lett. 110, 051103 (2017)

I. Prencipe, A. Sgattoni, D. Dellasega, L. Fedeli, L. Cialfi, Il Woo Choi, I Jong Kim, K. A. Janulewicz, K. F. Kakolee, Hwang Woon Lee, Jae Hee Sung, Seong Ku Lee, Chang Hee Nam and M Passoni,
*Development of foam-based layered targets for laser-driven ion beam production,*
Plasma Phys. Control. Fusion 58 (2016) 034019 (8pp)

M. Passoni, A. Sgattoni, I. Prencipe, L. Fedeli, D. Dellasega, L. Cialfi, Il Woo Choi, I Jong Kim, K. A. Janulewicz, Hwang Woon Lee, Jae Hee Sung, Seong Ku Lee, and Chang Hee Nam,
*Toward high-energy laser-driven ion beams: Nanostructured double-layer targets,*
PHYSICAL REVIEW ACCELERATORS AND BEAMS 19, 061301 (2016)

A. Maffini, A. Uccello, D. Dellasega and M. Passoni,
*Laser cleaning of diagnostic mirrors from tungsten–oxygen tokamak-like contaminants,*
Nucl. Fusion 56 (2016) 086008 (9pp)

E. Besozzi D. Dellasega, A. Pezzoli, C. Conti, M. Passoni and M. G. Beghi,
*Amorphous, ultra-nano- and nano-crystalline tungsten-based coatings grown by Pulsed Laser Deposition: mechanical characterization by Surface Brillouin Spectroscopy,*
Materials & Design 106 (2016): 14-21

L. Cialfi, L. Fedeli and M. Passoni,
*Electron heating in subpicosecond laser interaction with overdense and near-critical plasmas,*
Physical Review E 94.5 (2016): 053201