Modeling Nanostructured Plasmas For Superintense Laser-Plasma Interaction Experiments

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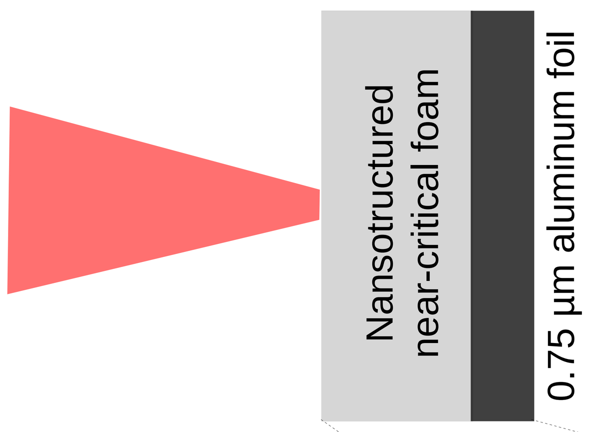
Nanostructured targets for laser-plasma experiments

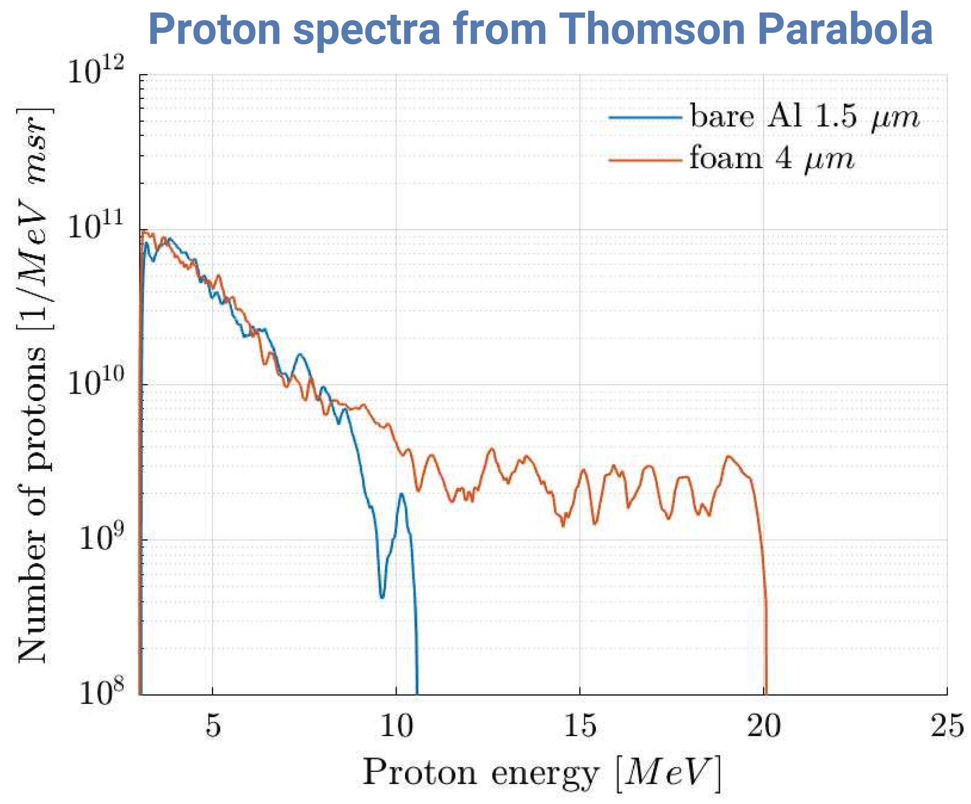
Laser parameters (DRACO 200 TW)

- Energy on target = 2 J
- Intensity = up to 5 x 10^{20} W/cm^2
- Angle of incidence = 2°
- High temporal contrast (>10^{12})

Double-layer Target scheme



Proton spectra from Thomson Parabola



Enhanced TNSA

- Near-critical layer → enhanced laser coupling
- More and hotter electrons
- More accelerated ions
- Higher cut-off energy

Nanostructured targets do work!

- Factor x2 in cutoff energy
- Factor x4 in proton number

Theoretical understanding required

- How to select best foam parameters (density, thickness, …)?
- What is the role of foam nanostructure?

in collaboration with: HZDR

I. Principe, T. Cowan, U. Schramm et al.

M. Passoni et al., Phys Rev Acc Beams 19 (2016)

Goal: improved modeling of laser-nanostructures interaction

Accurate description of nanostructured targets

Modeling the synthesis of nanofoam materials
3D PIC simulations with a realistic nanostructured plasma

Investigate the role of the nanostructure

Parametric scan with PIC simulations
Same average density, different nanostructure

3D PIC simulation of nanostructures: issues and challenges

Nanostructures are inherently 3D!

- 2D works fine to get some insights, but the structure has to be dramatically simplified
- 3D is required to faithfully capture the structure and get more accurate results

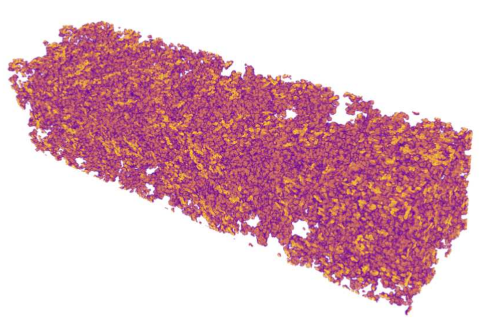
A "typical" 3D PIC simulations of laser-nanostructure interaction

	Real nanoparticles	Simulated nanoparticles
Radius	~10 nm	~40 nm
Density	~200 n_c	~60 n_c

Computational time
~10 hours on 64 nodes, 36 cores/node → **>20 kCPUhours**

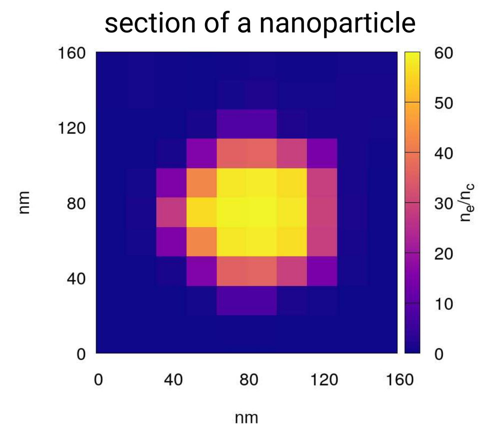
RAM memory
~17 x 10^9 particles + ~10^{10} grid points → **~1 TB for each time-step**

Storage memory
save data every 10 λ/c → **~ 10 TB for each simulation**

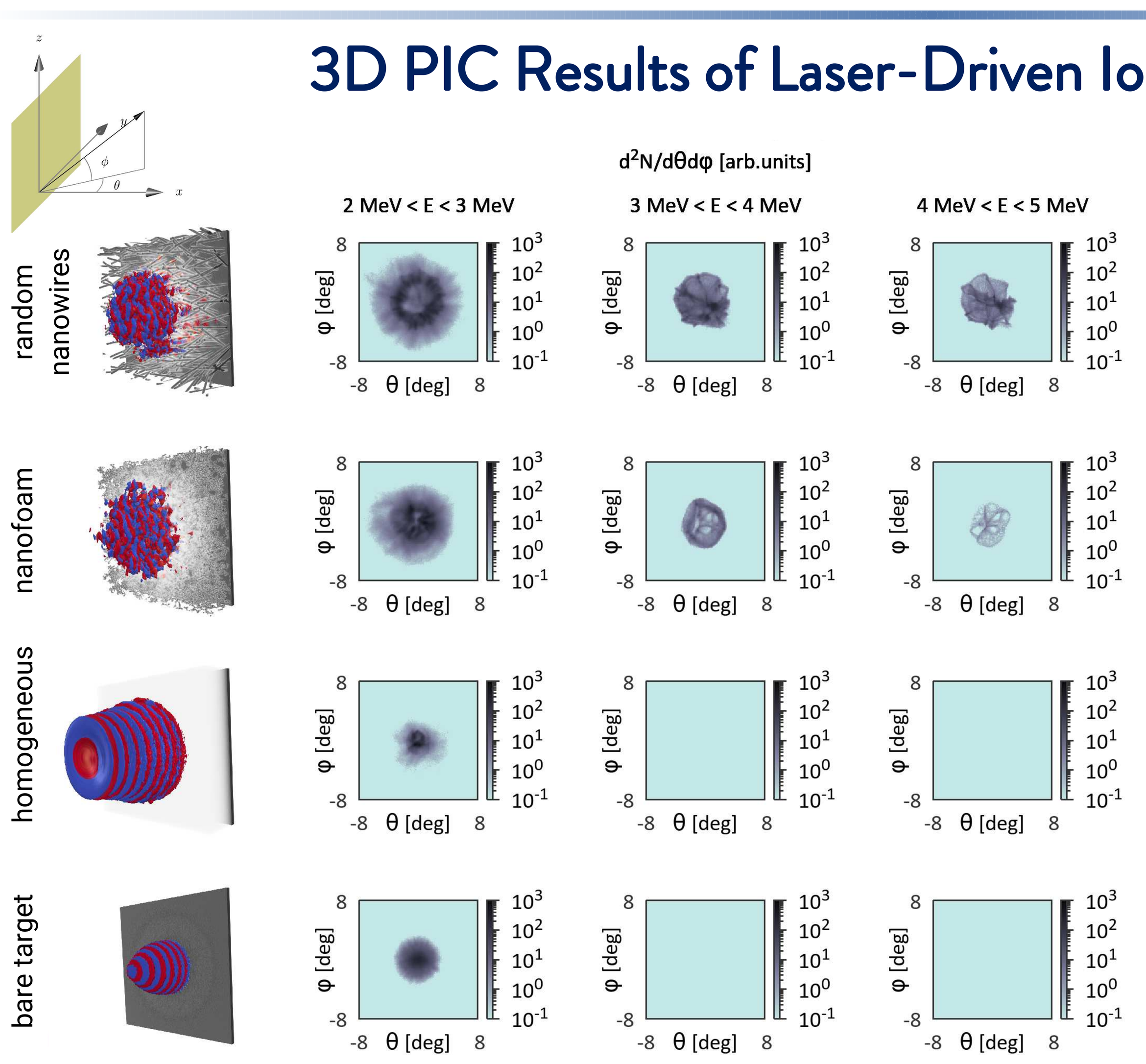


Simulation time < 100 λ/c
Window size < 100 λ
Resolution < 60 points/λ

section of a nanoparticle



3D PIC Results of Laser-Driven Ion Acceleration



some specs

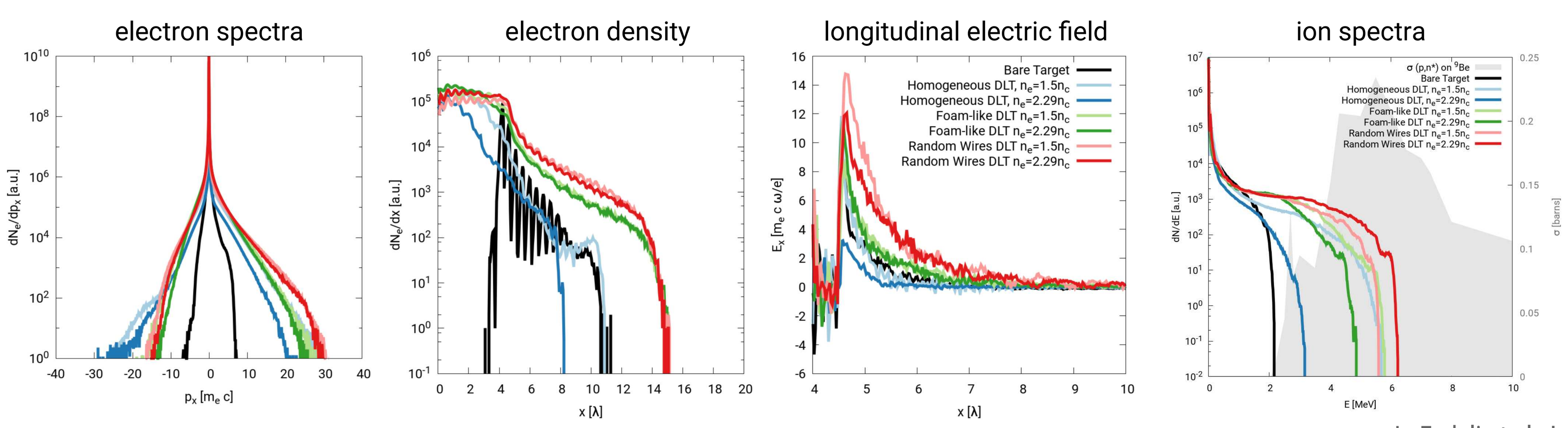
laser pulse
- λ = 0.8 µm
- a_0 = 4 (~ 10 TW)
- 30 fs duration
- 4 µm waist
- 0° incidence
- P-polarization

foams
- DLCCA model
- NPs: 32 nm, 40 n_c
- filling factor ~ 4-6%
- $<n_e>$ ~ 2 n_c
- 3.2 µm thickness

substrate
- n_e = 40 n_c
- 400 nm thickness

In summary:

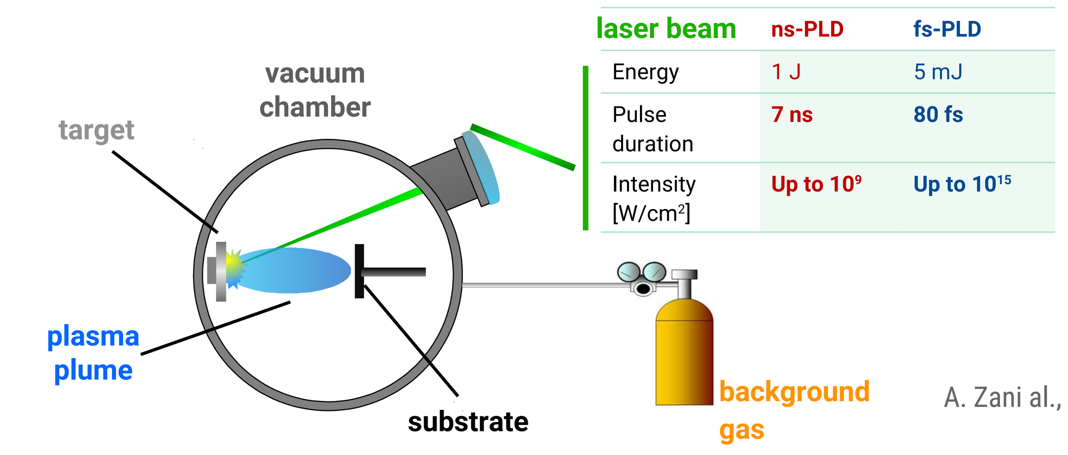
- Nanostructure matters!
- Nanostrucutred targets less sensitive to density change
- Double Layer Target better than bare foil
- Potential interest for applications (e.g. neutron generation)



L. Fedeli et al., In preparation

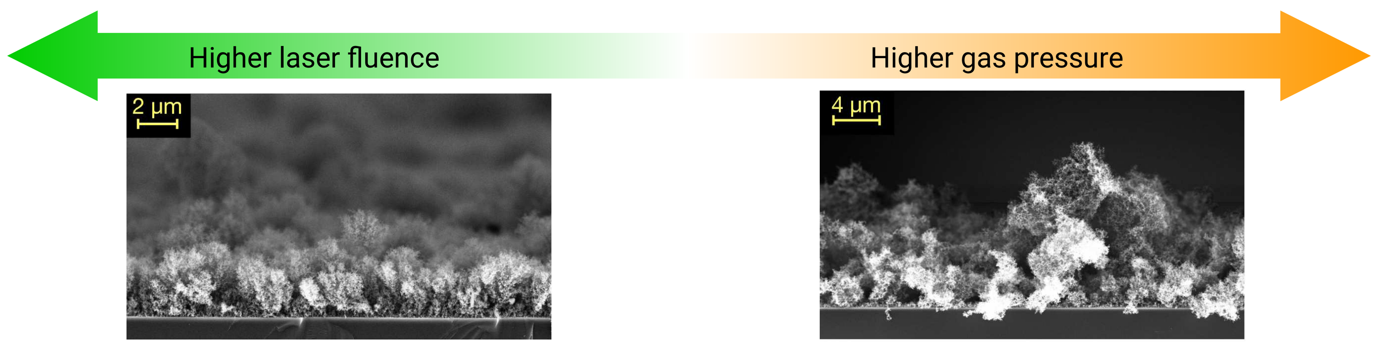
Carbon-based nanostructured materials

Pulsed Laser Deposition: a versatile tool for nanostructured materials deposition



PLD
- Different deposition regimes
- Wide space of parameters
- Any kind of substrate

A. Zani al., Carbon 56 (2013) 358



Tree-like material

- Building block: 10 nm nanoparticles
- Ballistic aggregation
- Density ~ 15 nc

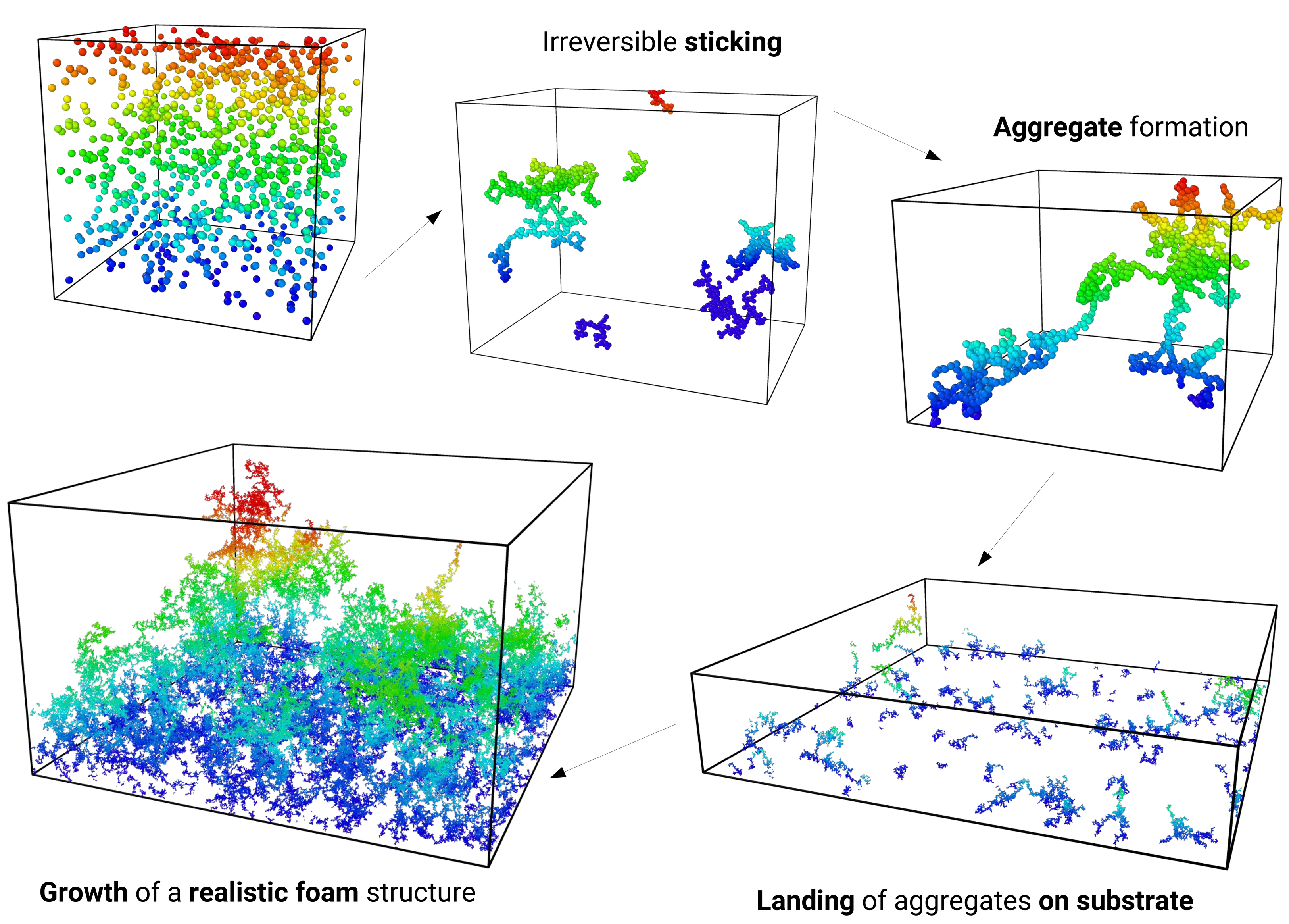
Foam-like material

- Building block: 10 nm nanoparticles
- "Snowfall model" aggregation
- Density ~ 3 nc

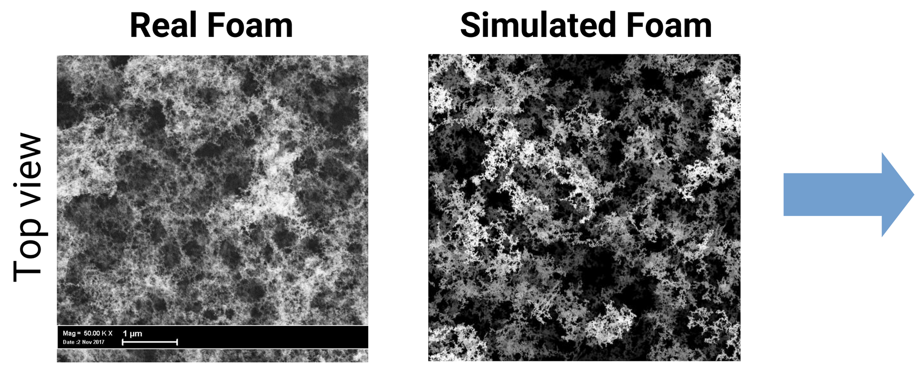
A. Maffini et al., Phys. Rev. Mater., accepted (2019)

Modelling nanofoam structure

A numerical model of foam growth inspired by experimental observations



Real nanostructures are accurately reproduced



Input of PIC simulation
- Save particles coordinates
- Save particles radii
- Import in PIC
- Sample with PIC macroparticles
- Initialize as a fully-ionized C plasma

L. Fedeli et al., Sci. Rep. 8 (2018)

Conclusions

Modeling of nanofoam materials

A numerical model of foam aggregation to reproduce morphology and nanostructure

PIC simulations of laser-nanostructures interaction

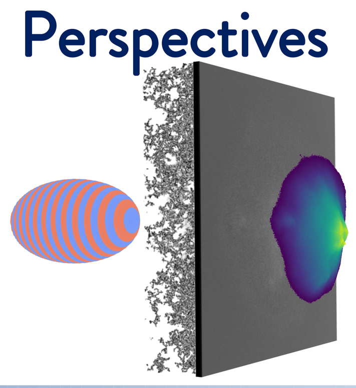
Combined and integrated 2D and 3D simulations is the most convenient solution

3D PIC simulation for ion acceleration with nanostructured targets

- The nanostructure has to be included for complete description of the process
- Nanostructure engineering may enable novel applications of laser-driven ion beams

Perspectives

Target optimization & design of new experiments



PIC simulations to support experiment interpretation

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