Nanostructured Targets For Laser-driven Ion Acceleration And Its Applications

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INTRODUCTION

Enhanced laser-driven ion acceleration via near-critical materials

conventional foil
- 10^{-2} – 10 μm thickness
- solid density

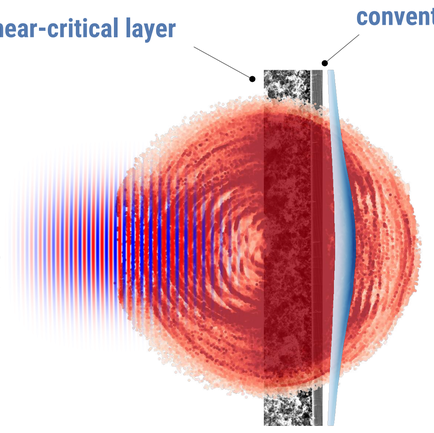
hot electrons
- thermal spectrum
- 1 – 10 MeV temperature

superintense laser
- 10 – 10^3 TW
- 10 – 10^3 fs
- 0.1 – 10 J
- 10^{18} – 10^{22} W/cm^2

accelerated ions
- exponential spectrum
- maximum energy < 100 MeV/A
- 10^8 – 10^{12} ions/bunch
- ps duration

switch to a smarter target

exploit the strong laser-matter coupling at the critical density



improved acceleration
- bigger and hotter electron cloud!
- more ions accelerated at higher energies!

Near-critical nanostructured double-layer targets

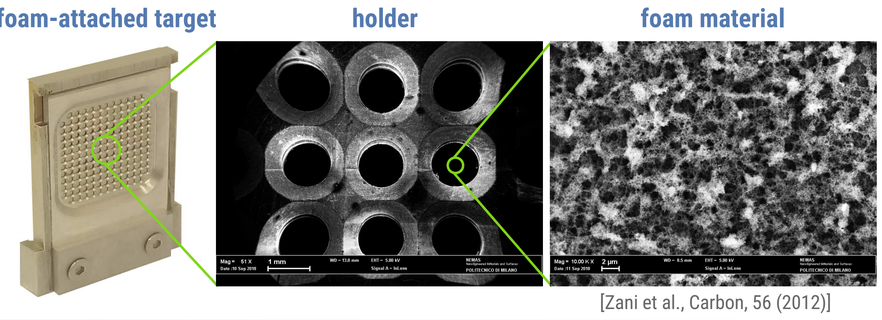
$$n_c(\omega) = \frac{m_e \omega^2}{4\pi e} \longleftrightarrow \rho_c(\lambda) = \frac{1.87}{\lambda^2[\mu\mathrm{m}]} \left(\frac{A}{Z}\right) \frac{\mathrm{mg}}{\mathrm{cm}^3}$$

e.g. for carbon and $\lambda_{Ti:Sa}$~0.8 μm → ρ_c~ 6 mg/cm^3 << air density!

nanostructured carbon foams as one of the very few low-density, solid state materials thanks to their extremely low filling factor

[Passoni et al., Phys. Rev. Acc. Beams, 19.6 (2016)]

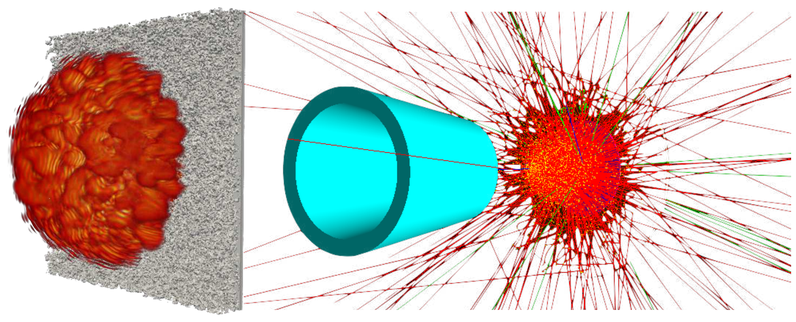
foam-attached target **holder** **foam material**



[Zani et al., Carbon, 56 (2012)]

GOALS

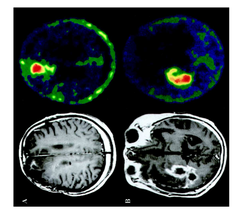
Develop a theoretical/numerical description...



from laser-plasma interaction to secondary radiation sources

...to investigate the potential applications

- exploit unconventional features
  - non-monochromatic ion energy
  - pulsed & short ion source
  - same laser, multiple applications
- reduce laser requirements
- design experiments
- optimize configurations



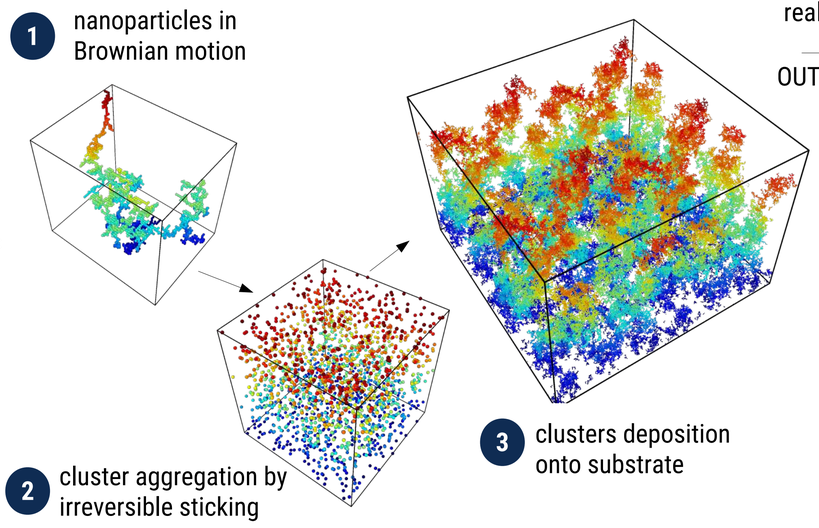
METHODS

Integrated multi-stage and multi-scale approach

[Fedeli et al., Sci. Rep., 8 (2018)]

Nanostructure and morphology description through a Diffusion Limited Cluster-Cluster Aggregation model

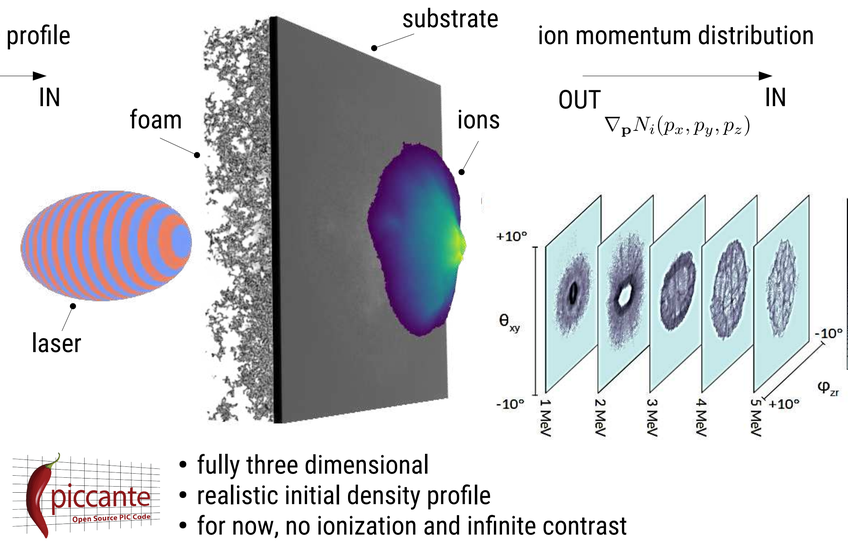
1. nanoparticles in Brownian motion
2. cluster aggregation by irreversible sticking
3. clusters deposition onto substrate



Particle-In-Cell simulations of laser-driven ion acceleration

realistic density profile: OUT ← $\rho(x,y,z)$ → IN

ion momentum distribution: OUT ← $\nabla_{\mathbf{p}} N_i(p_x,p_y,p_z)$ → IN

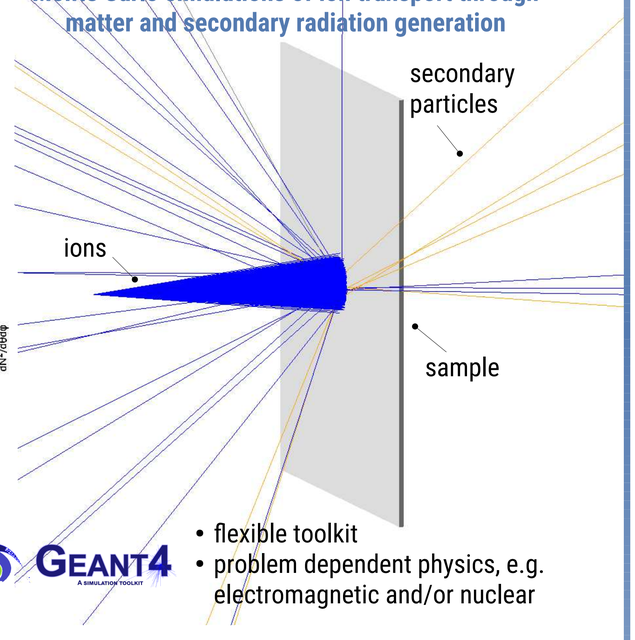


piccante Open Source PIC Code

- fully three dimensional
- realistic initial density profile
- for now, no ionization and infinite contrast

[Passoni et al., Sci. Rep., *accepted* (2019)]

Monte Carlo simulations of ion transport through matter and secondary radiation generation



GEANT4 A SIMULATION TOOLKIT

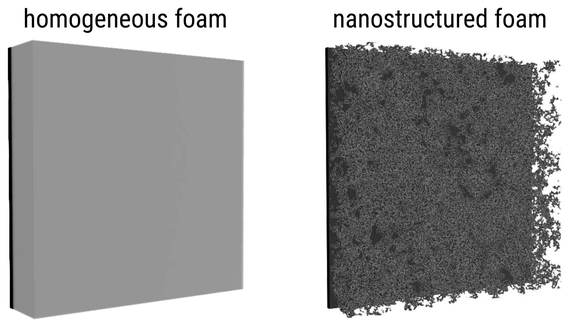
- flexible toolkit
- problem dependent physics, e.g. electromagnetic and/or nuclear

RESULTS

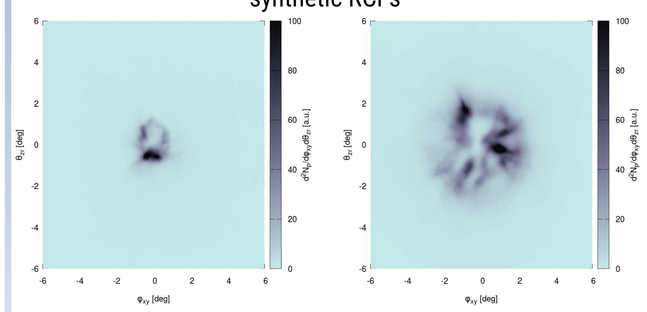
Role of the nanostructure & neutron generation

double-layer targets (DLT)

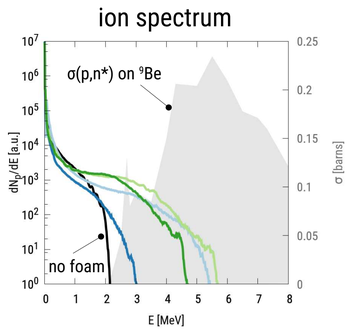
homogeneous foam | nanostructured foam



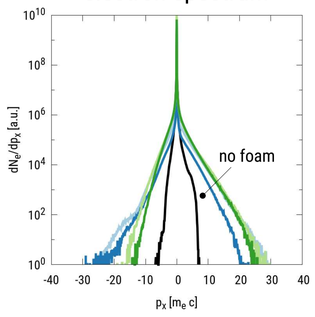
synthetic RCFs



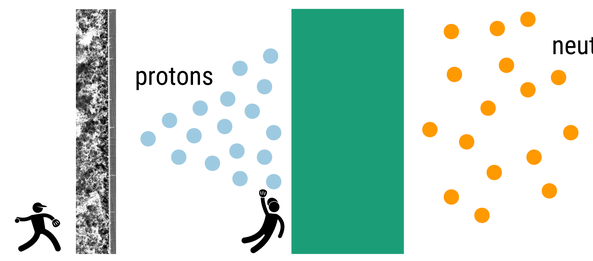
ion spectrum



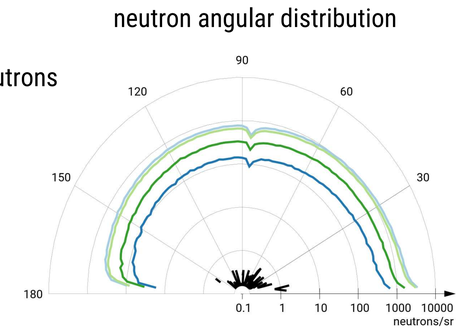
electron spectrum



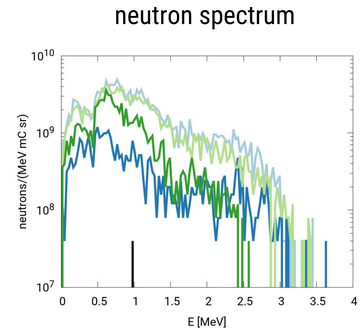
foam-attached target | p-to-n converter



neutron angular distribution



neutron spectrum



legend

- no foam
- homogeneous foam: n_e=1.5n_c, n_e=2.3n_c
- nanostructured foam: n_e=1.5n_c, n_e=2.3n_c

some specs

laser pulse
- λ = 0.8 μm
- a_0 = 4
- ~ 10 TW
- 30 fs duration
- 4 μm waist
- normal incidence
- P-polarization

foams
- DLCCA model
- $\langle n_e \rangle$ = 1.5 n_c & 2.3 n_c
- 3.2 μm thickness
- filling factor ~ 4-6%
- A/Z = 2 → C^{6+}
- 32 nm NP radius
- NP density = 40 n_c

substrate
- n_e = 40 n_c
- A/Z = 2 → Al^{13+}
- 400 nm thickness

converter
- ^{9}Be → (p,n) reactions
- thickness = range in Be of the most energetic p

CONCLUSIONS & PERSPECTIVES

- **FOAM-ATTACHED TARGETS**: to enhance ion acceleration process
- **INTEGRATED APPROACH**: to simulate from the interaction to the applications
- **ROLE OF THE NANOSTRUCTURE**: should be included for a complete description
- **NEUTRON GENERATION**: promising application that may be enabled by the foam

next steps…
- → include in the description other features (e.g. electron bremsstrahlung)
- → experimental campaigns on neutron generation
- → studies on laser-driven radioisotope production

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