Laser-driven ion acceleration enhanced by ultra-low density foam-attached targets and its applications

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Politecnico di Milano, Italy

European Research Council
Established by the European Commission

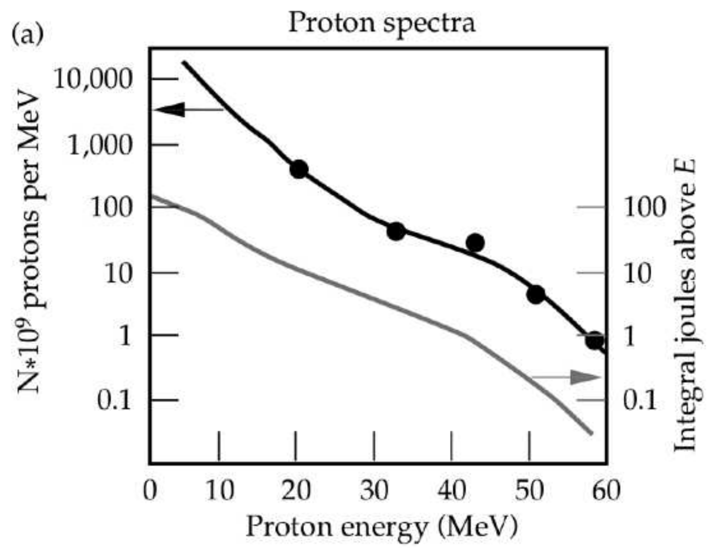
POLITECNICO MILANO 1863
DIPARTIMENTO DI ENERGIA

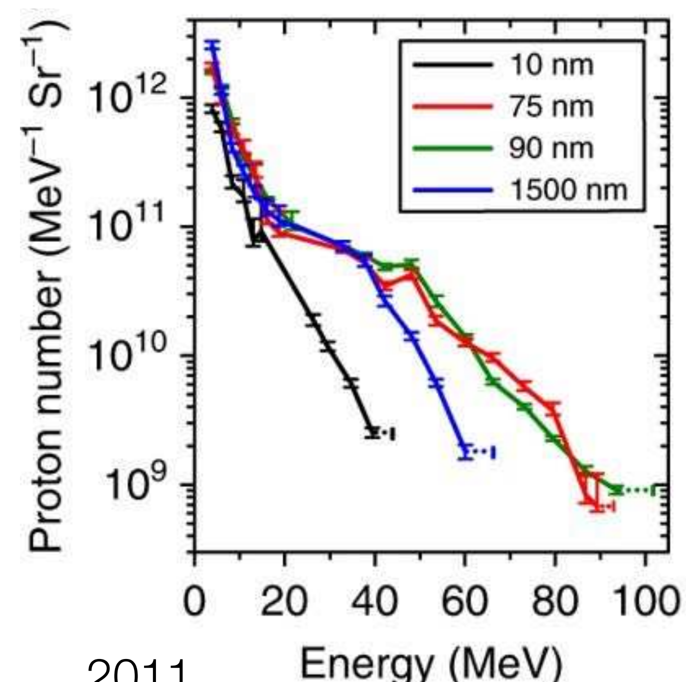
NanoLab

Breckenridge, Colorado, USA, August , 2018

Great improvements thanks to both progress in laser technology and clever target engineering

Snavely, PRL
58 MeV @ Nova
500J, 500fs, 1PW





Higginson, NatComm
near-100 MeV @ Vulcan
200J, 1ps , 200TW

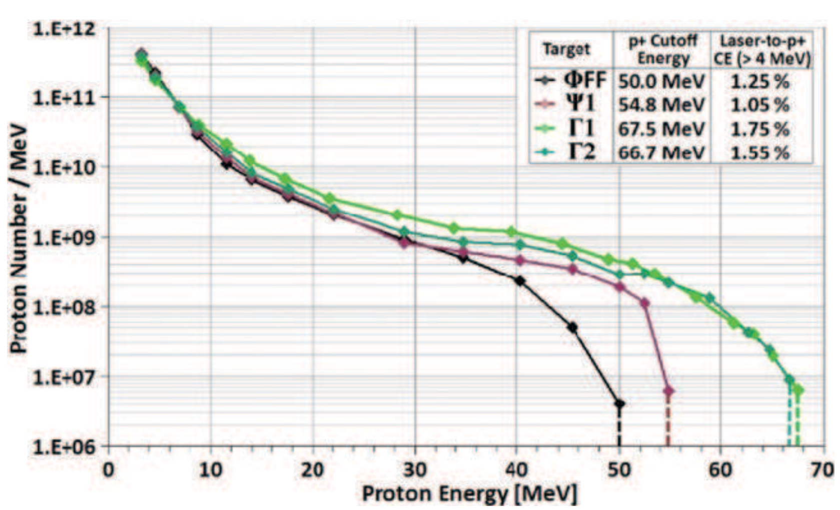
2000

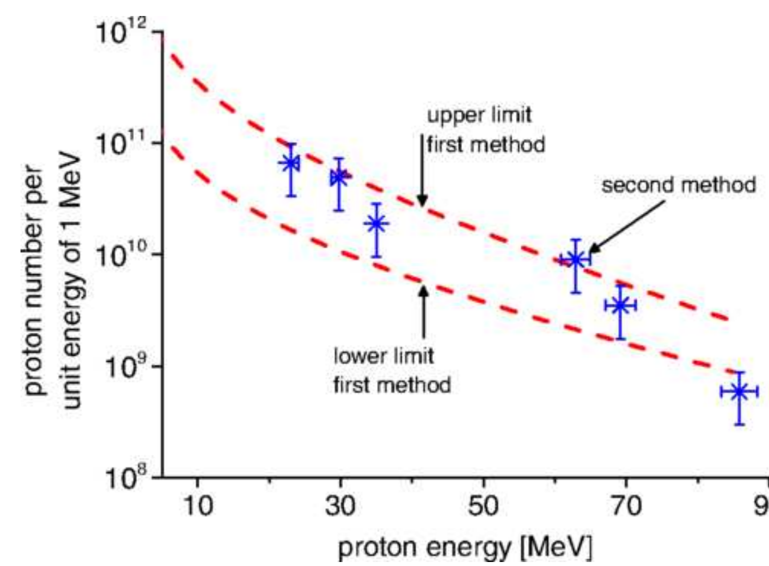
2011

2016

2018

Gaillard, PoP
67.5 MeV @ Trident
80J, 700fs, 200TW





Wagner, PRL
85 MeV @ PHELIX
200J, 0.5ps, 400TW

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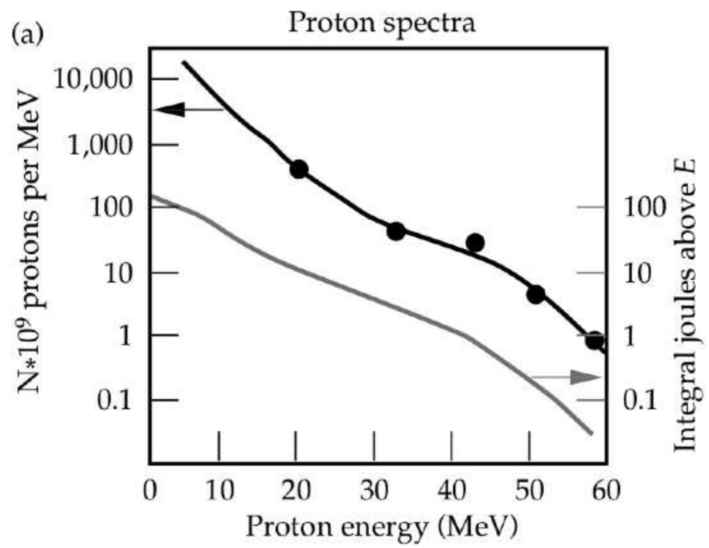

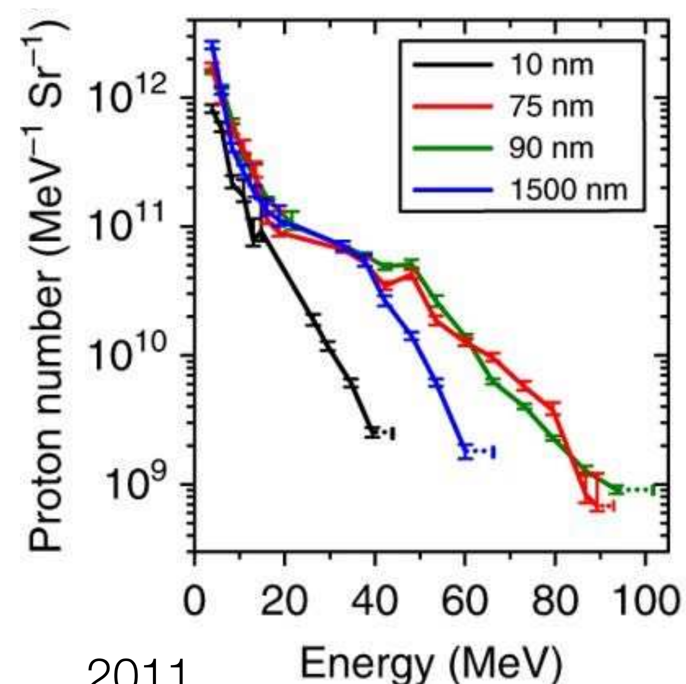

our approach

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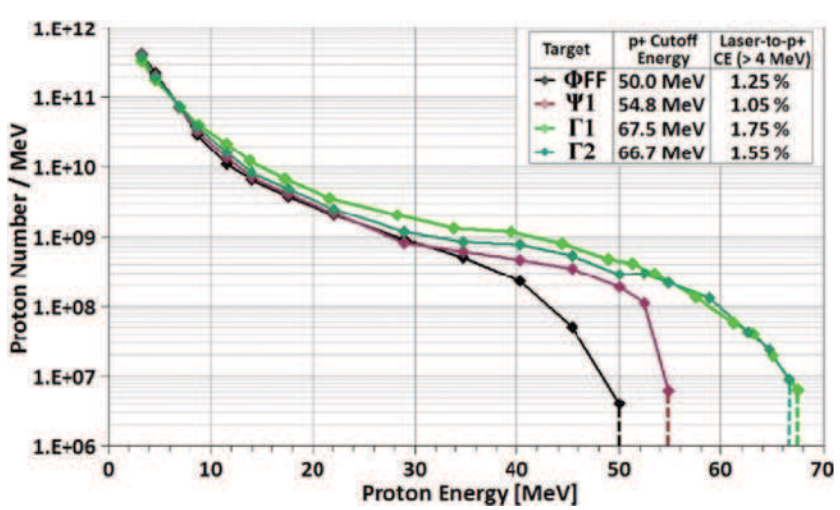

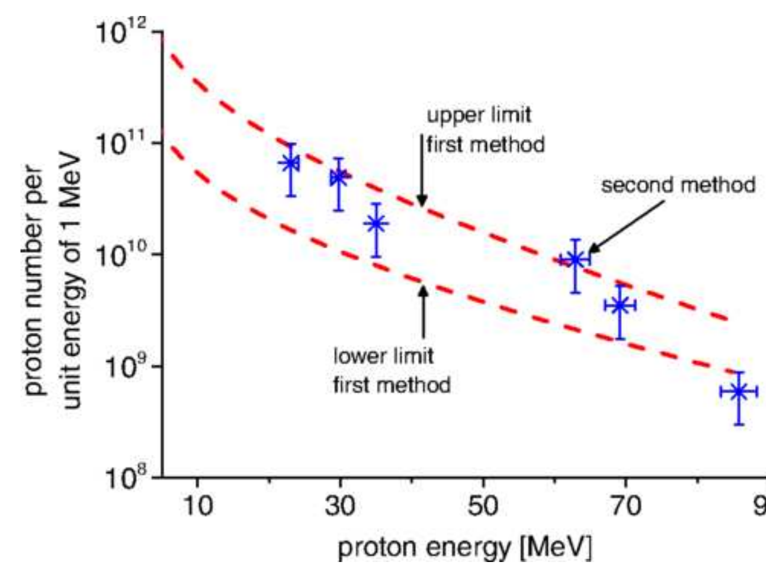

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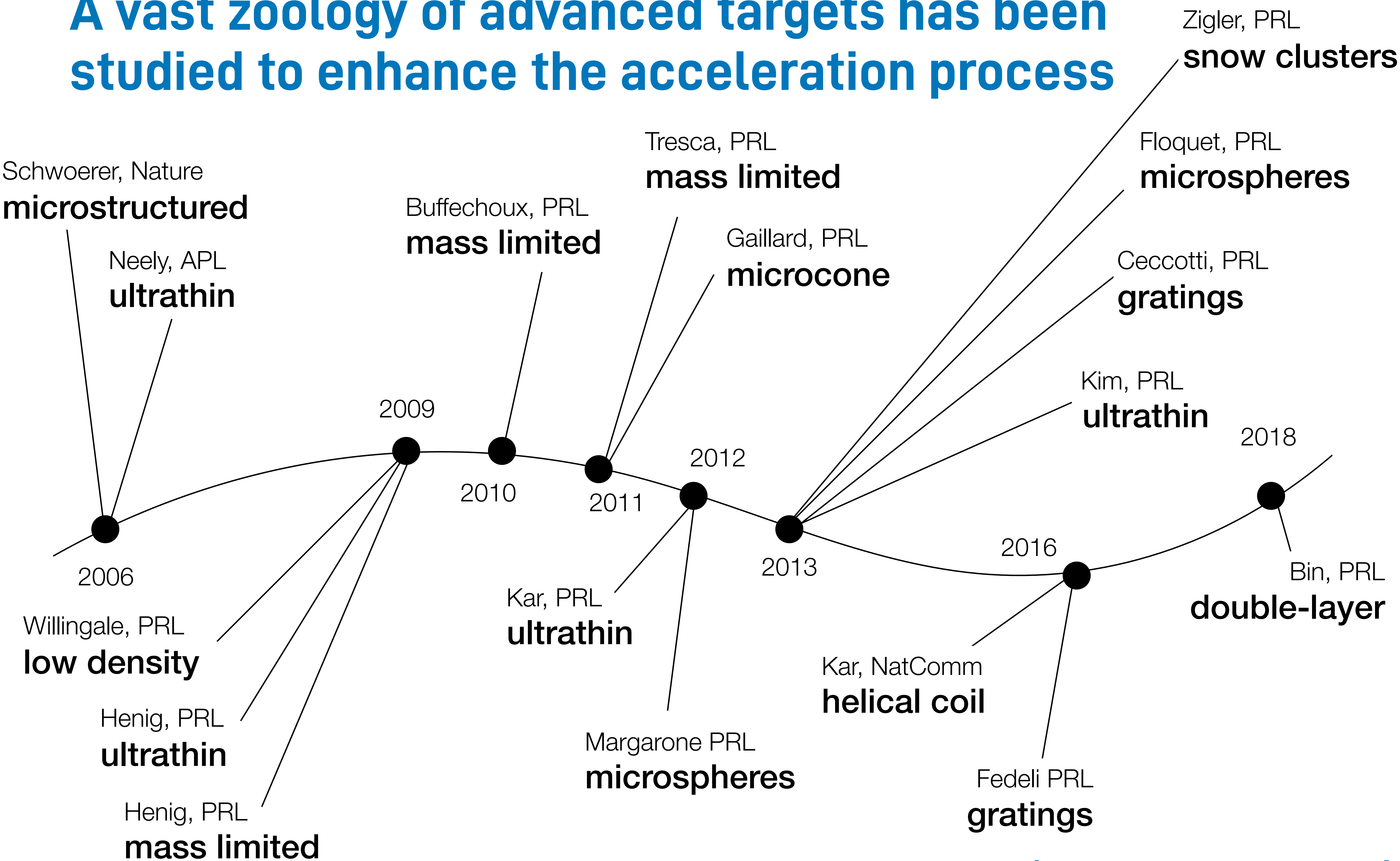
A vast zoology of advanced targets has been studied to enhance the acceleration process



...and many, many, many more!

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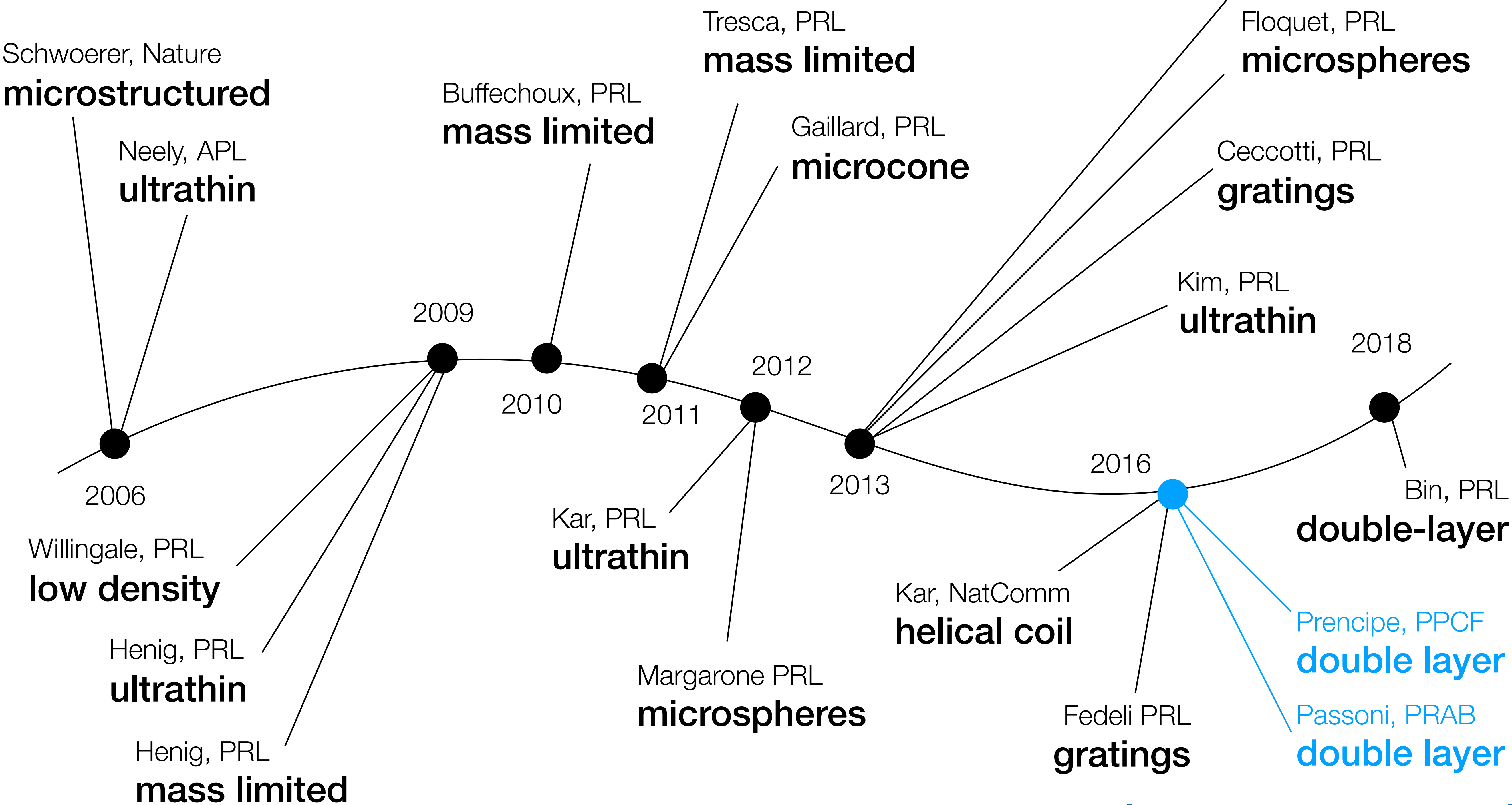


...and many, many, many more!

We are working on these topics at Politecnico di Milano, Italy

Fundings from the **European Research Council**

Consolidator Grant
ENSURE
ERC-2014-CoG No. 647554

Proof of Concept
INTER
ERC-2016-PoC No. 754916

POLITECNICO
MILANO 1863

Hosting Institution
Politecnico di Milano, Department of Energy, NanoLab

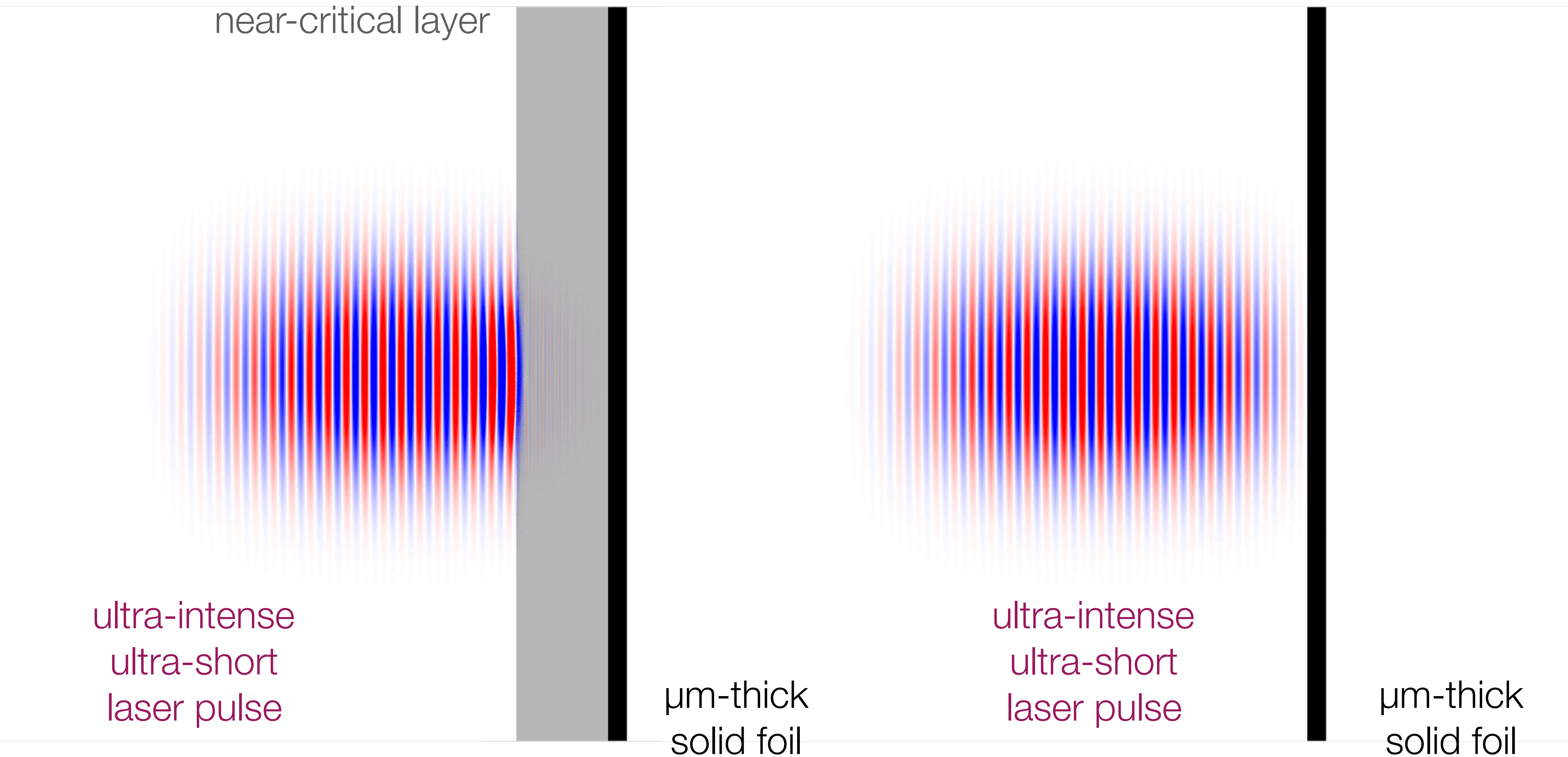
Principal Investigator
Matteo Passoni

Team
PI
2 associate professors
1 assistant professor
3 post-docs
3 PhD students
MSc students
support from NanoLab people

Enhanced TNSA via near-critical layer before the typical solid foil

t = 27 fs

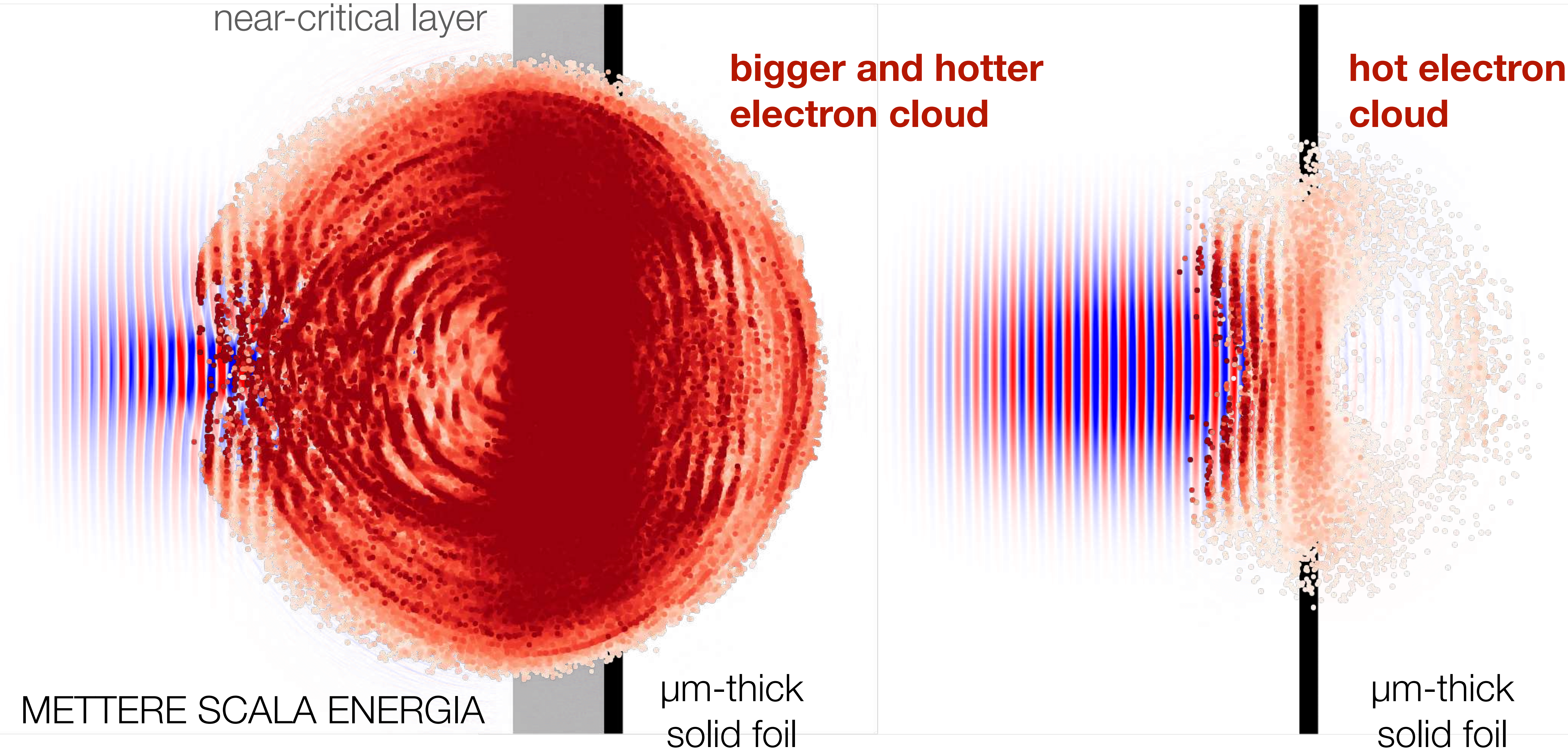
Enhanced TNSA | **Conventional TNSA**



The near-critical layer leads to an improved hot electron generation

t = 81 fs

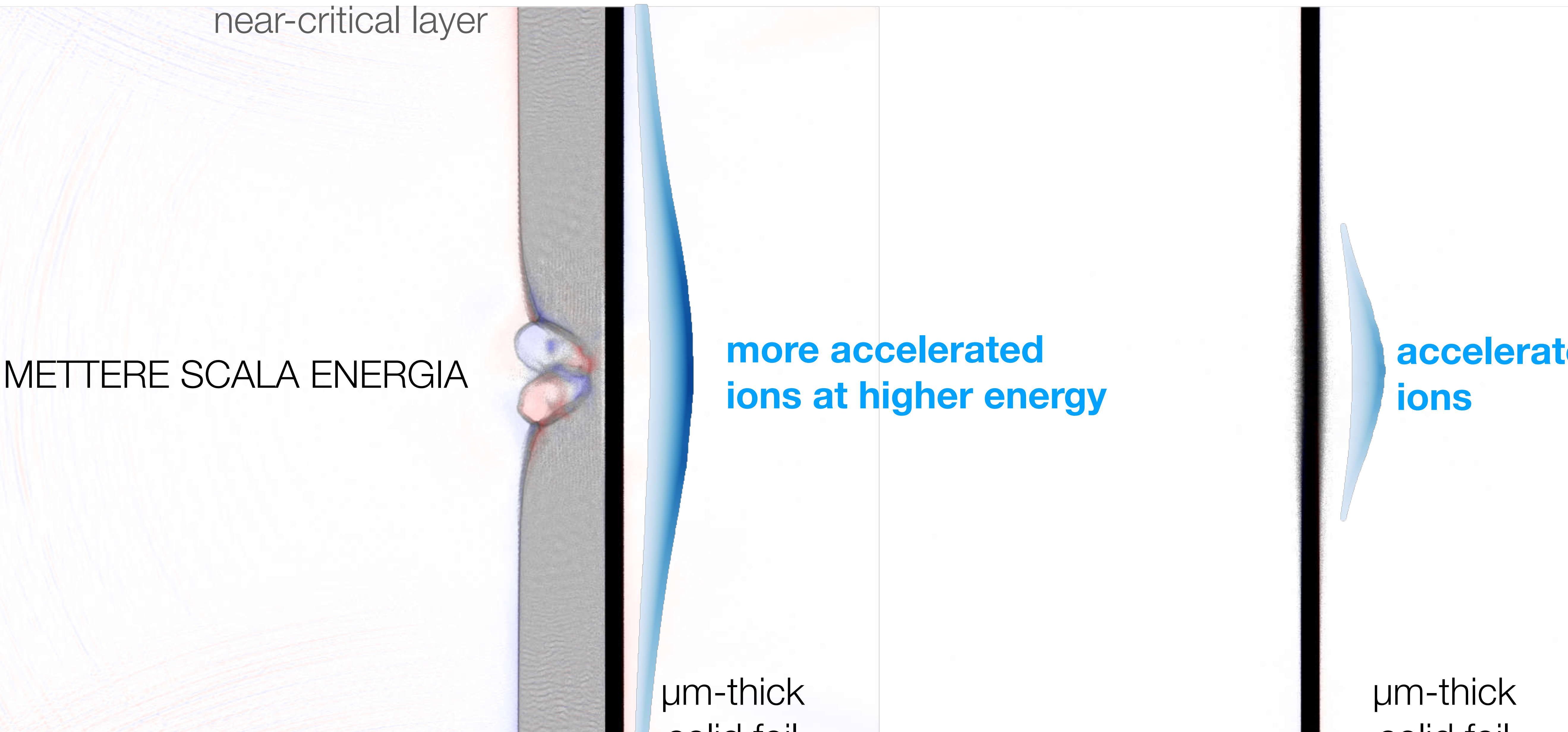
Enhanced TNSA **Conventional TNSA**



In turn you increase total number and maximum energy of the ions

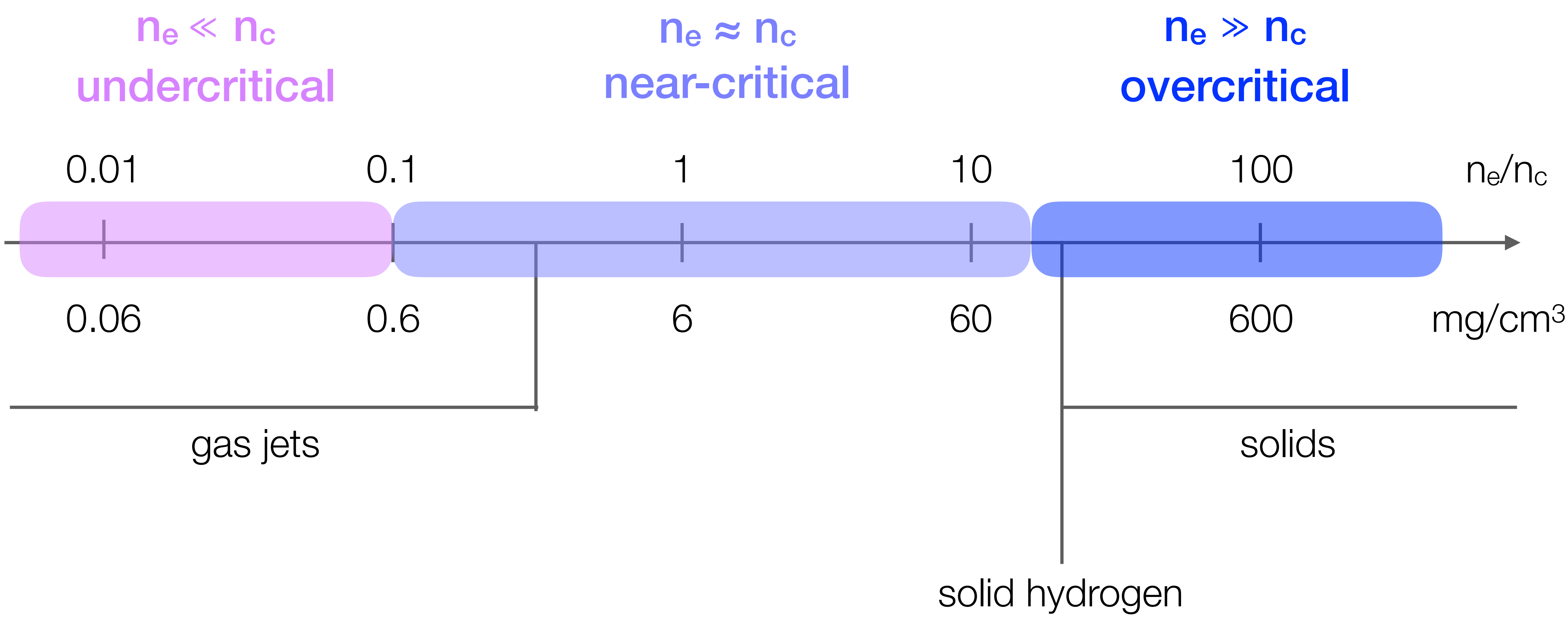
t = 189 fs

Enhanced TNSA | **Conventional TNSA**



Near-critical density for λ ~ 0.8 μm is in between typical gas and solid densities: challenging to obtain

$$\rho_c(\lambda) \simeq \frac{1.87}{\lambda^2[\mu m]}\left(\frac{A}{Z}\right)\frac{mg}{cm^3} \longrightarrow \lambda \sim 0.8\mu m \quad \rho_c \sim 6\frac{mg}{cm^3}$$



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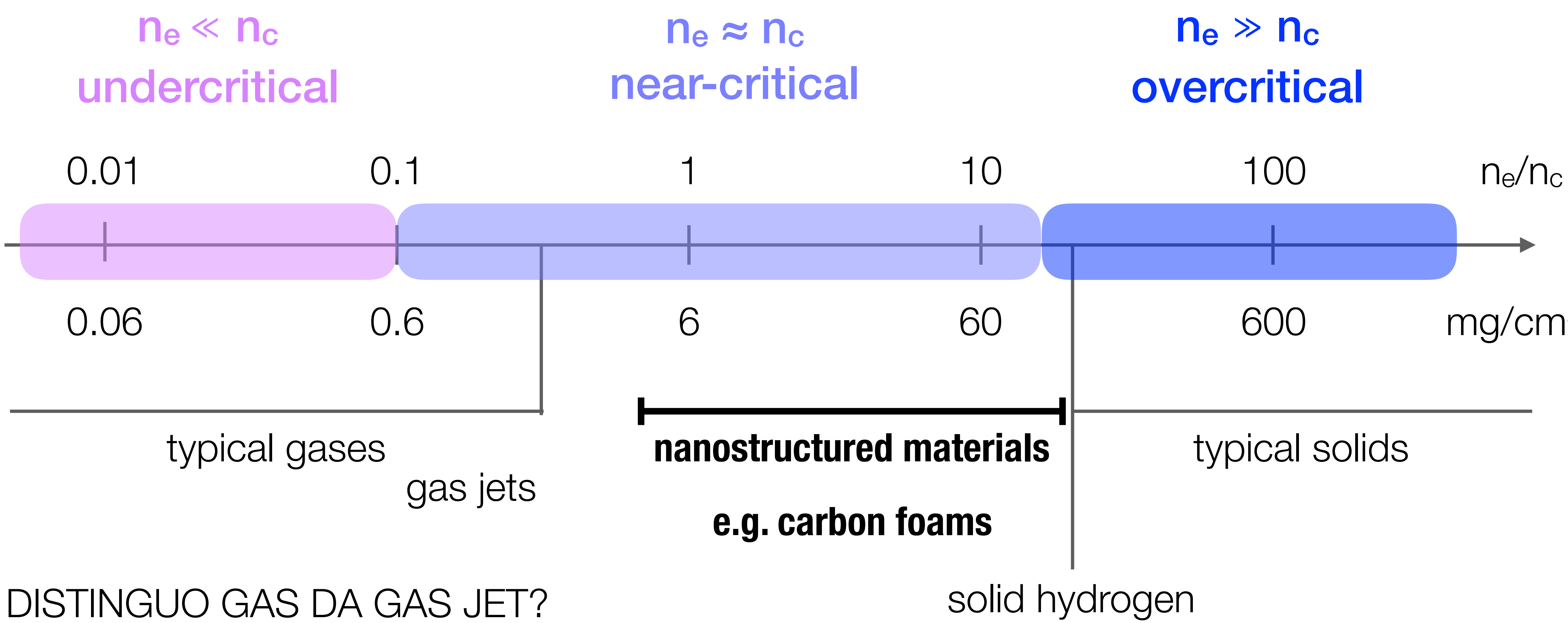
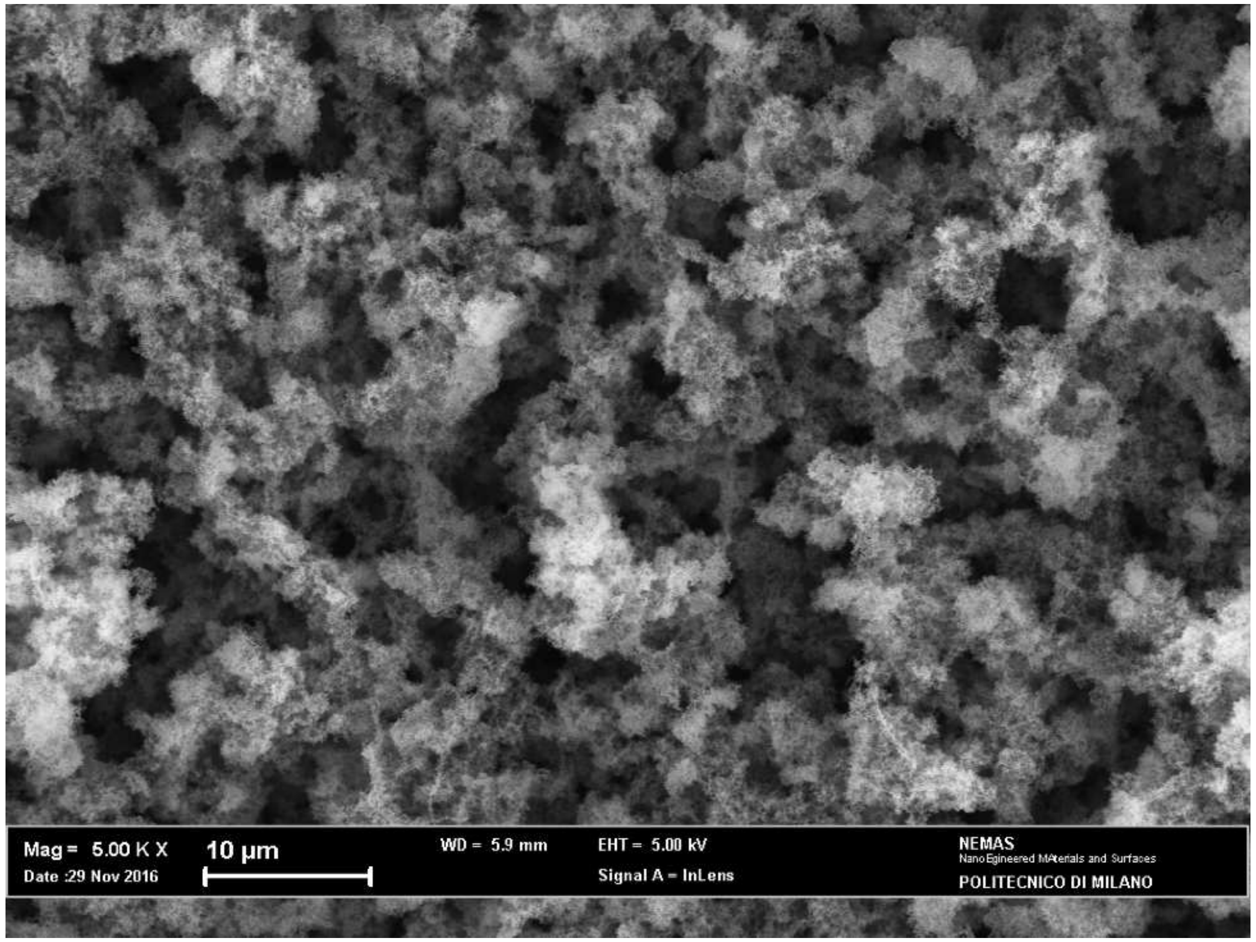


DISTINGUO GAS DA GAS JET?
SE Sì COLLOCARE GAS JET

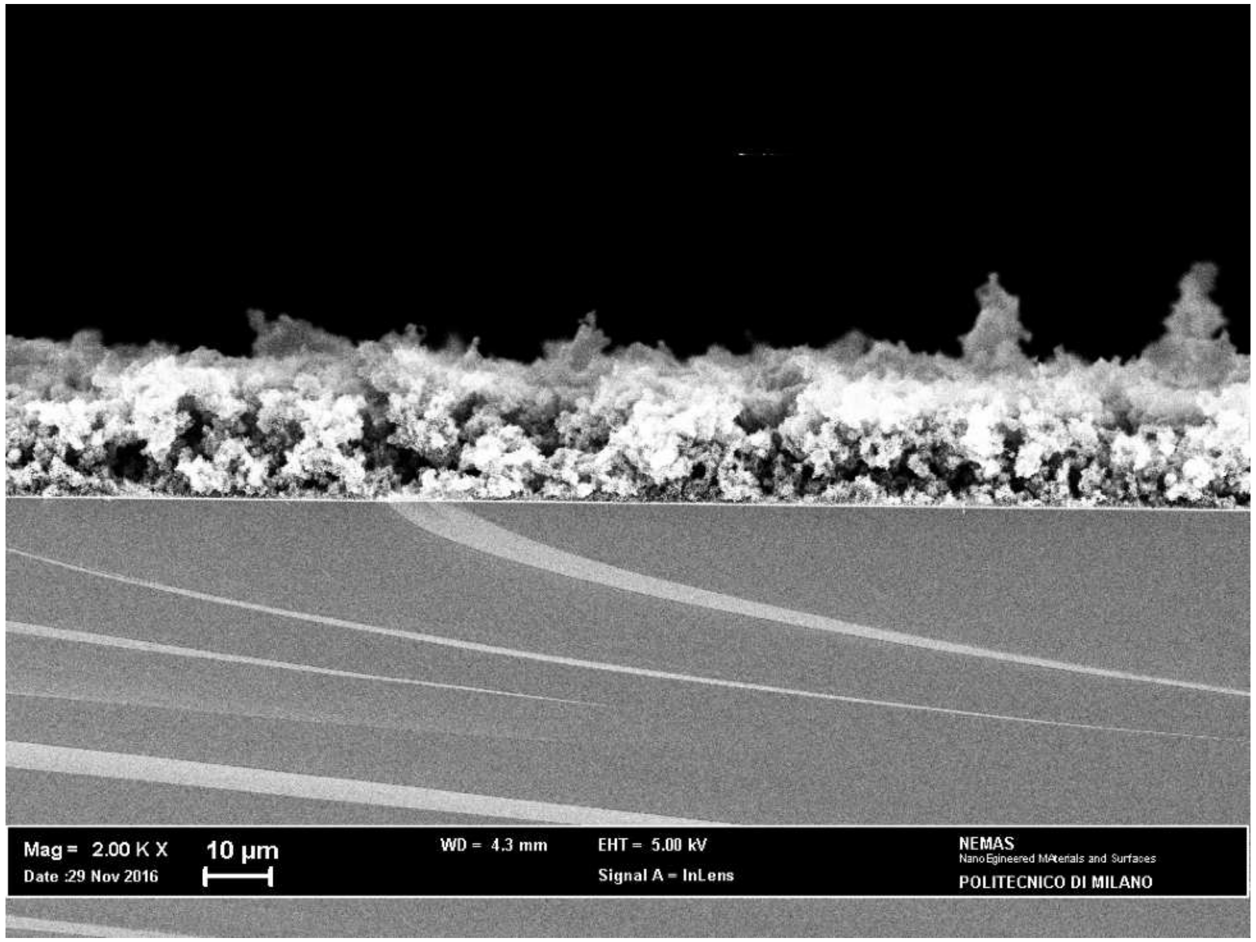
Carbon foams are one of the few solid near-critical materials for λ ~ 0.8 μm

dare numeri:
range densità media
raggio nanoparticelle

top view SEM image

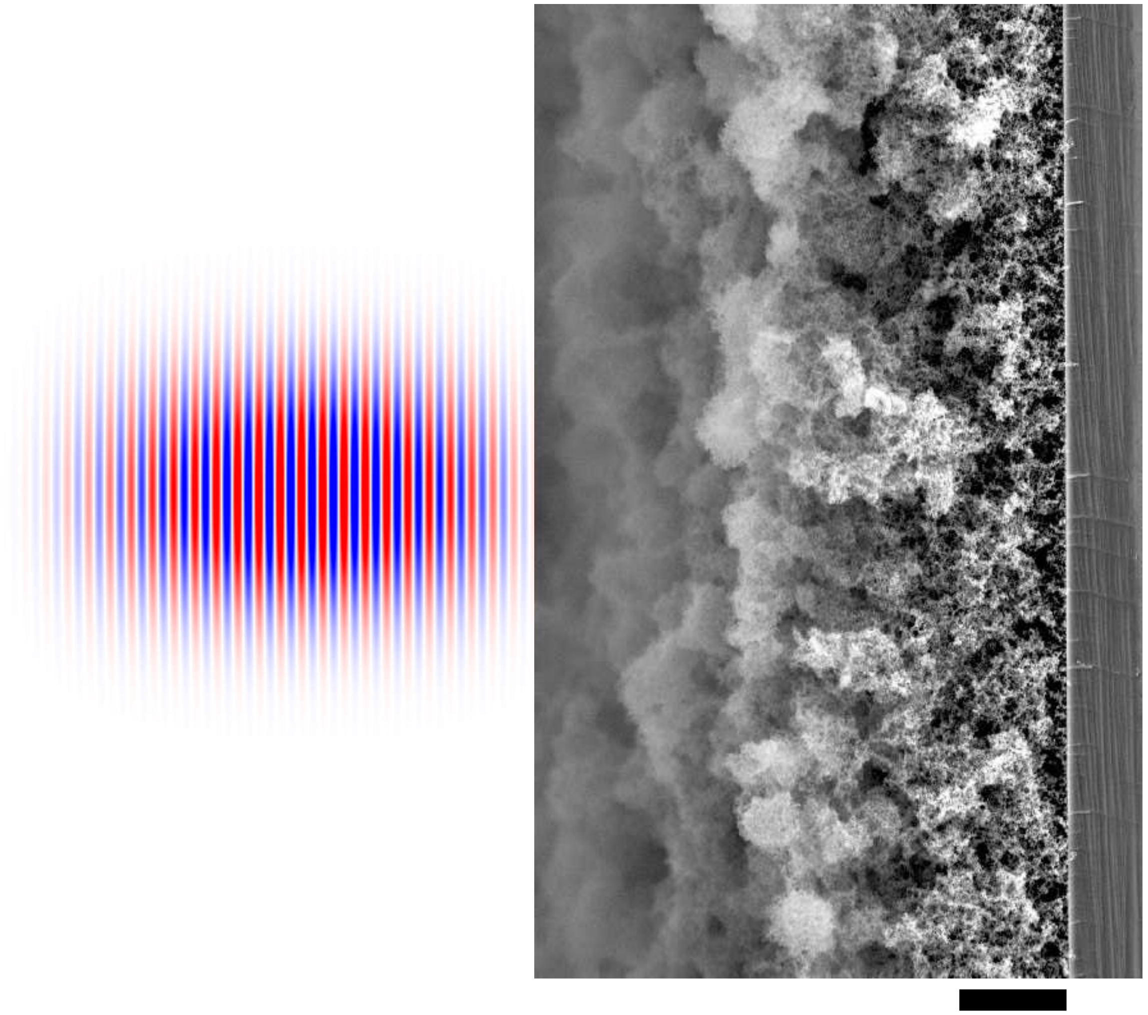


cross section SEM image



produced at NanoLab via Pulsed Laser Deposition technique

Enhanced TNSA with ultra-low density foam-attached targets



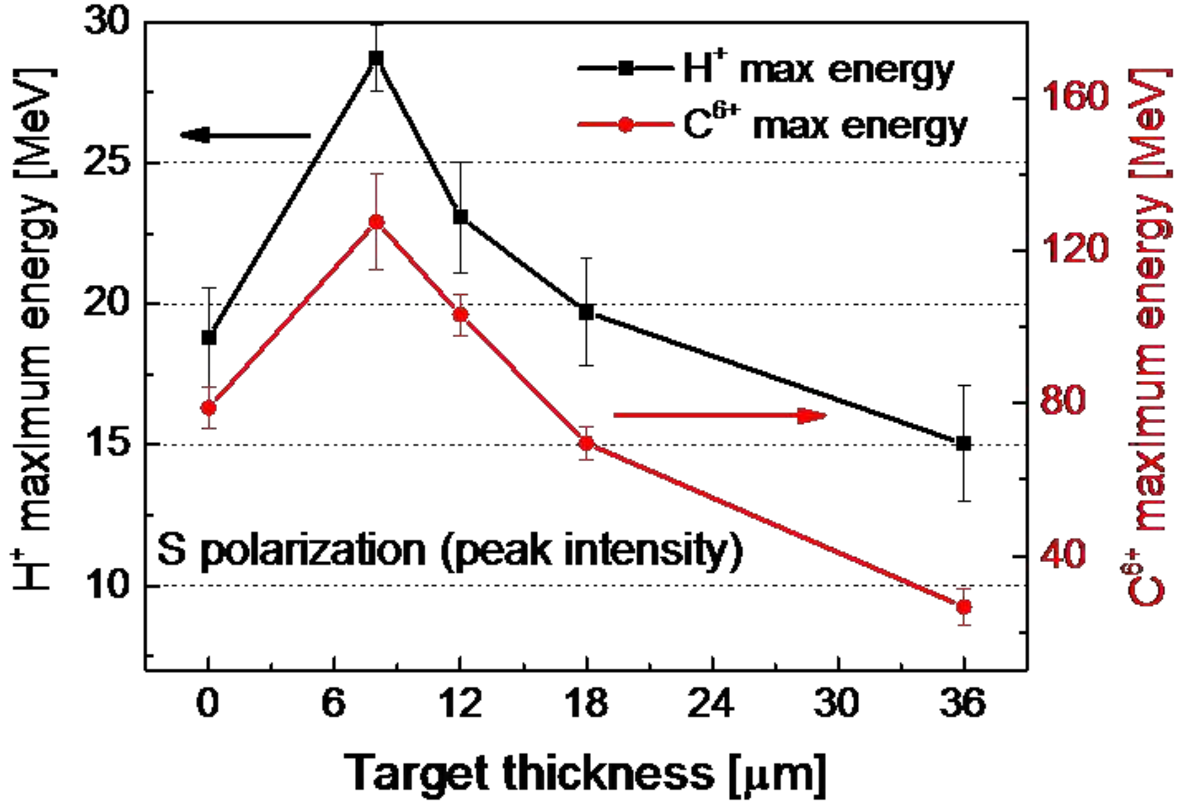
THE TARGET IS THE KEY

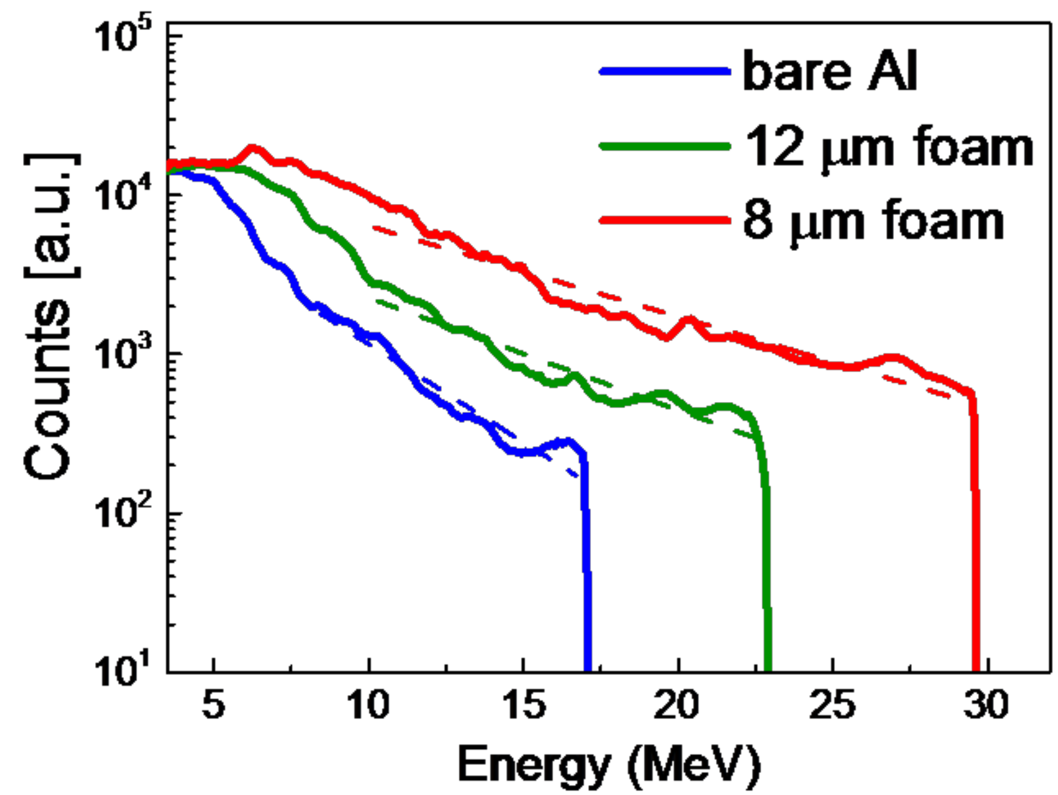
Experiments show a systematic increase of ion maximum energy and total charge

up to x 1.7 up to x 7

Gwangju Institute of Science and Technology

PULSER





Laser parameters
- 30 fs
- 7.4 J
- 4.5 x 10^{20} W/cm^2
- S polarization

Target parameters
- Al 0.75 μm substrate
- C 0, 8, 12 μm foam
- 7 mg/cm^3 foam density

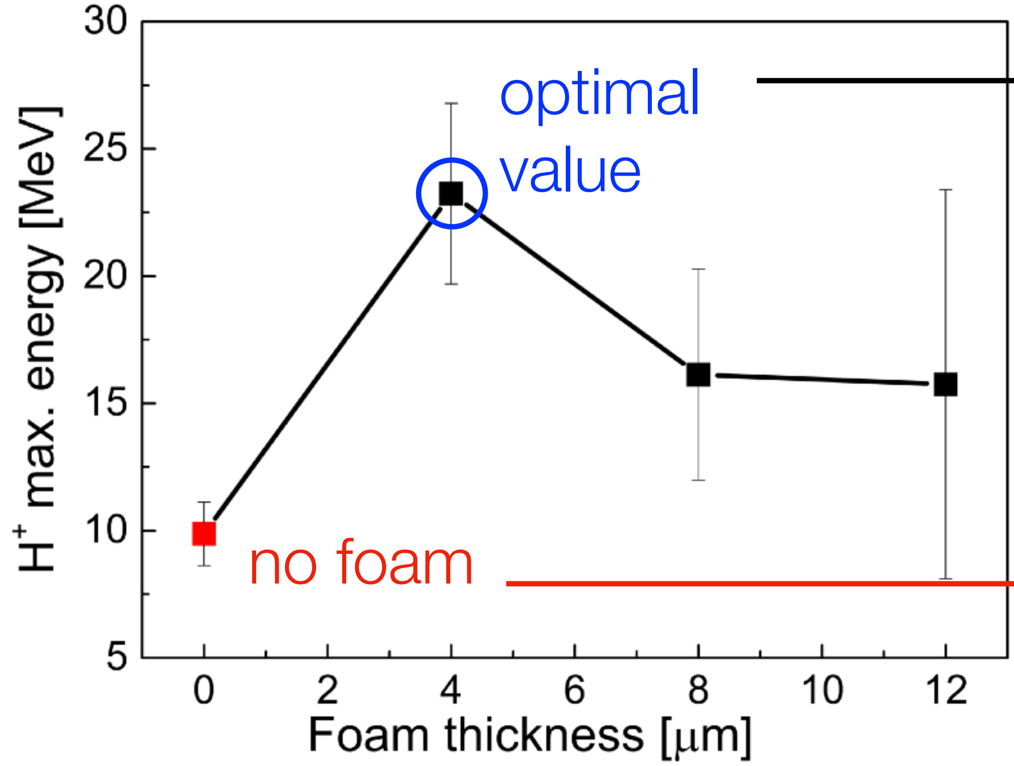
FORSE TIENI SOLO QUELLA DOPO

Experiments show a systematic increase of ion maximum energy and total charge

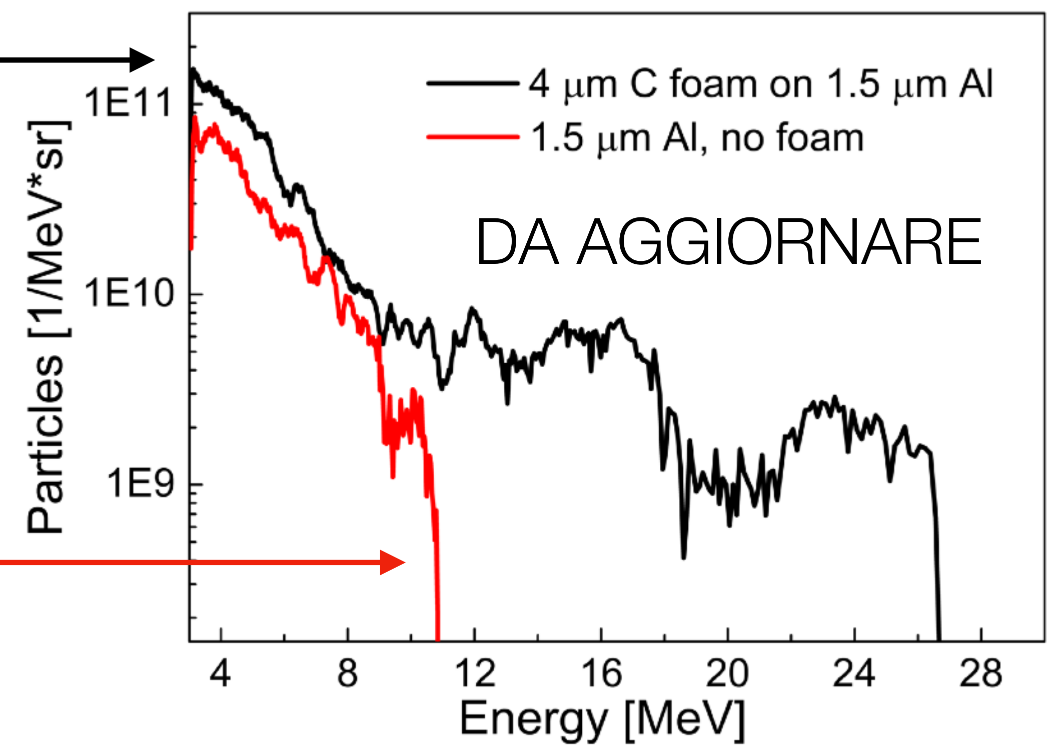
up to x 2 up to x BOH

DRACO

maximum proton energy vs. foam thickness



proton energy spectra



Laser parameters

- 2 J on target
- 5 x 10^{20} W/cm^2
- 150 TW
- 2° incidence

Target parameters

- Al 1.5 μm substrate
- C 4,8,12 μm foam
- 10 mg/cm^3 foam density

CHECK DENSITY

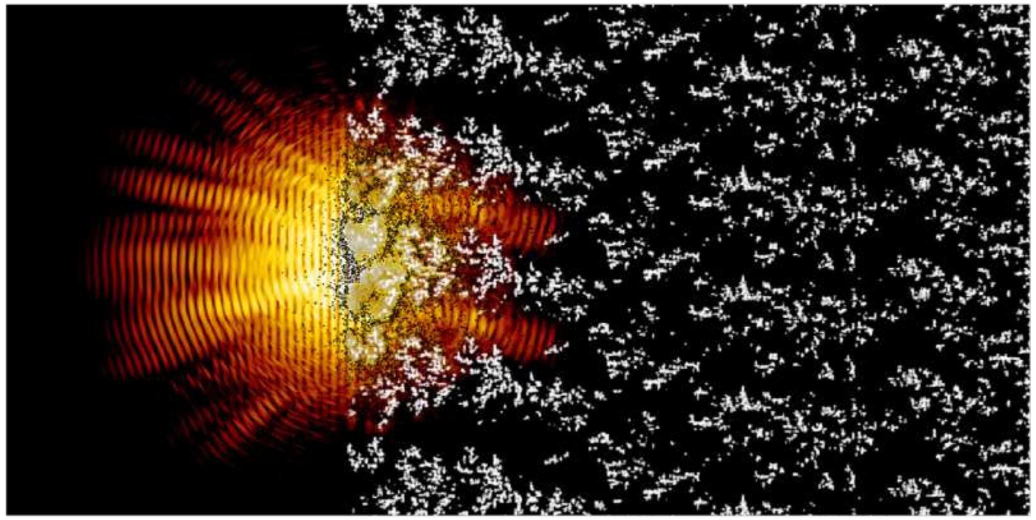
A better theoretical understanding of the physics at play is crucial to optimize the acceleration

How does the nanostructure influence the interaction and the acceleration processes?

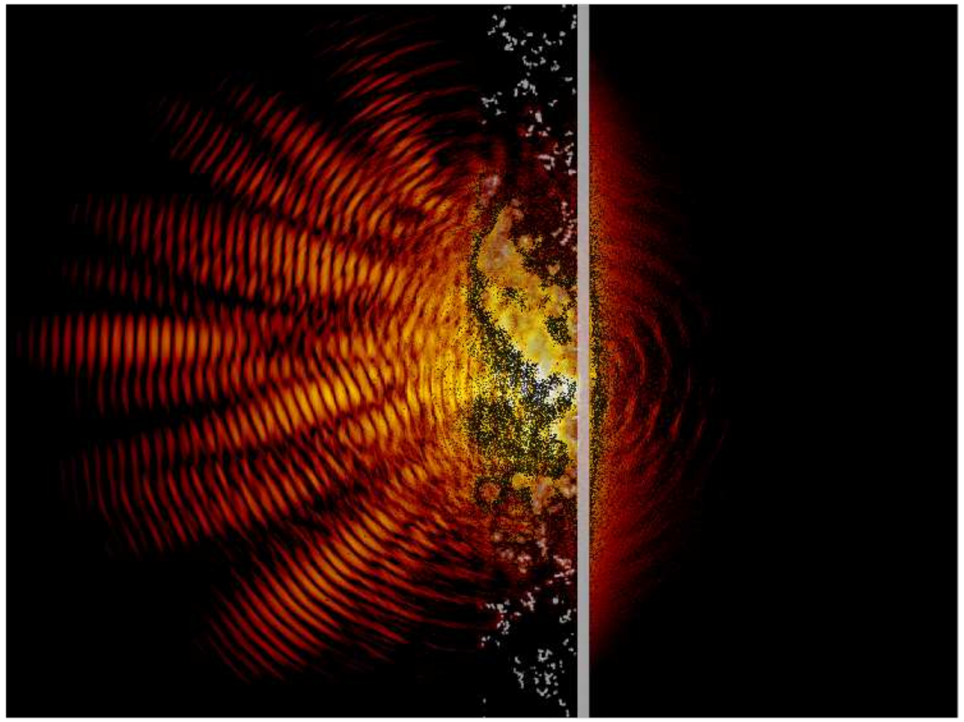
LOGO CINECA **3D Particle-In-Cell simulations**

piccante
Open Source PIC Code

laser-plasma interaction

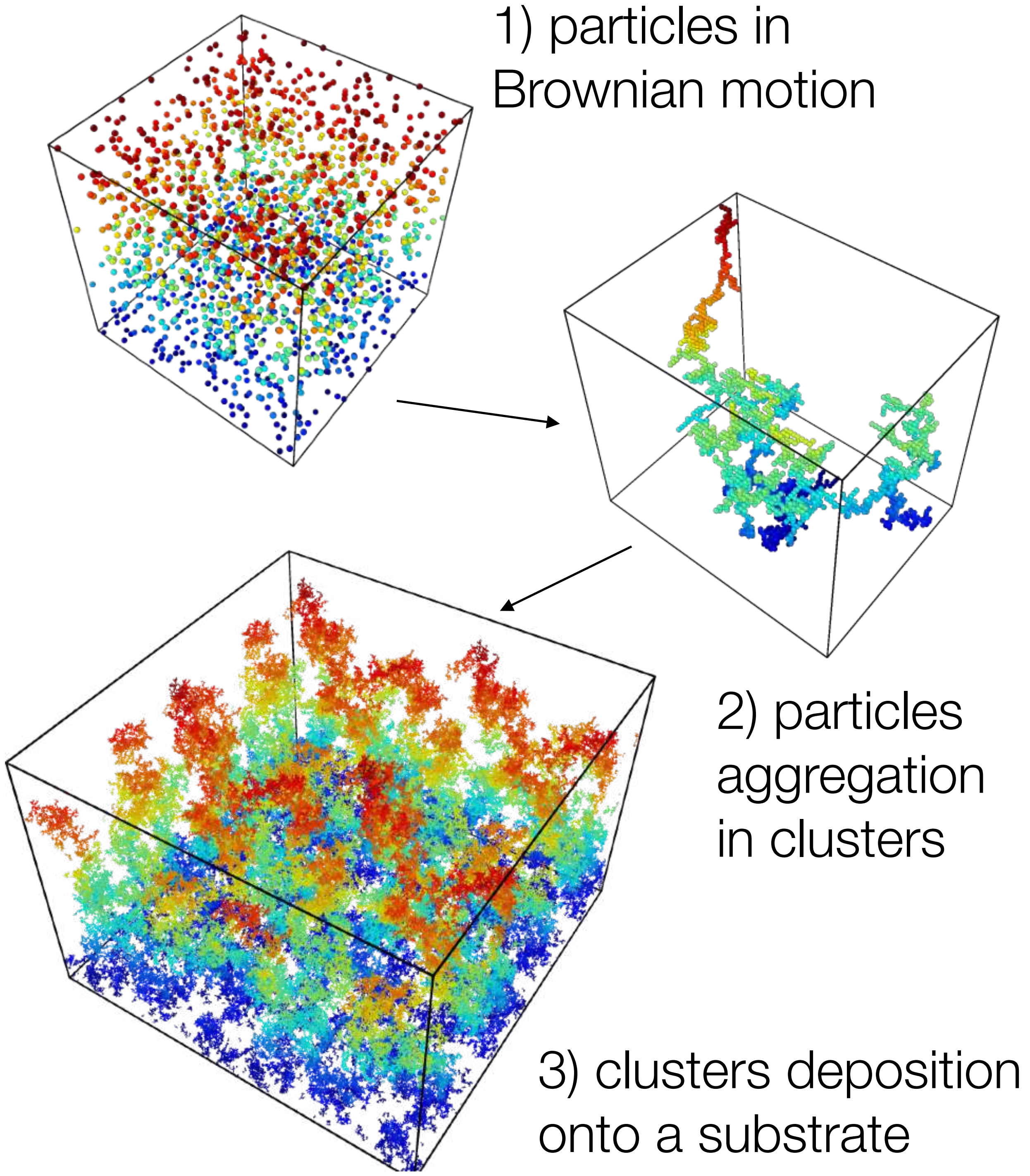


laser-driven ion acceleration

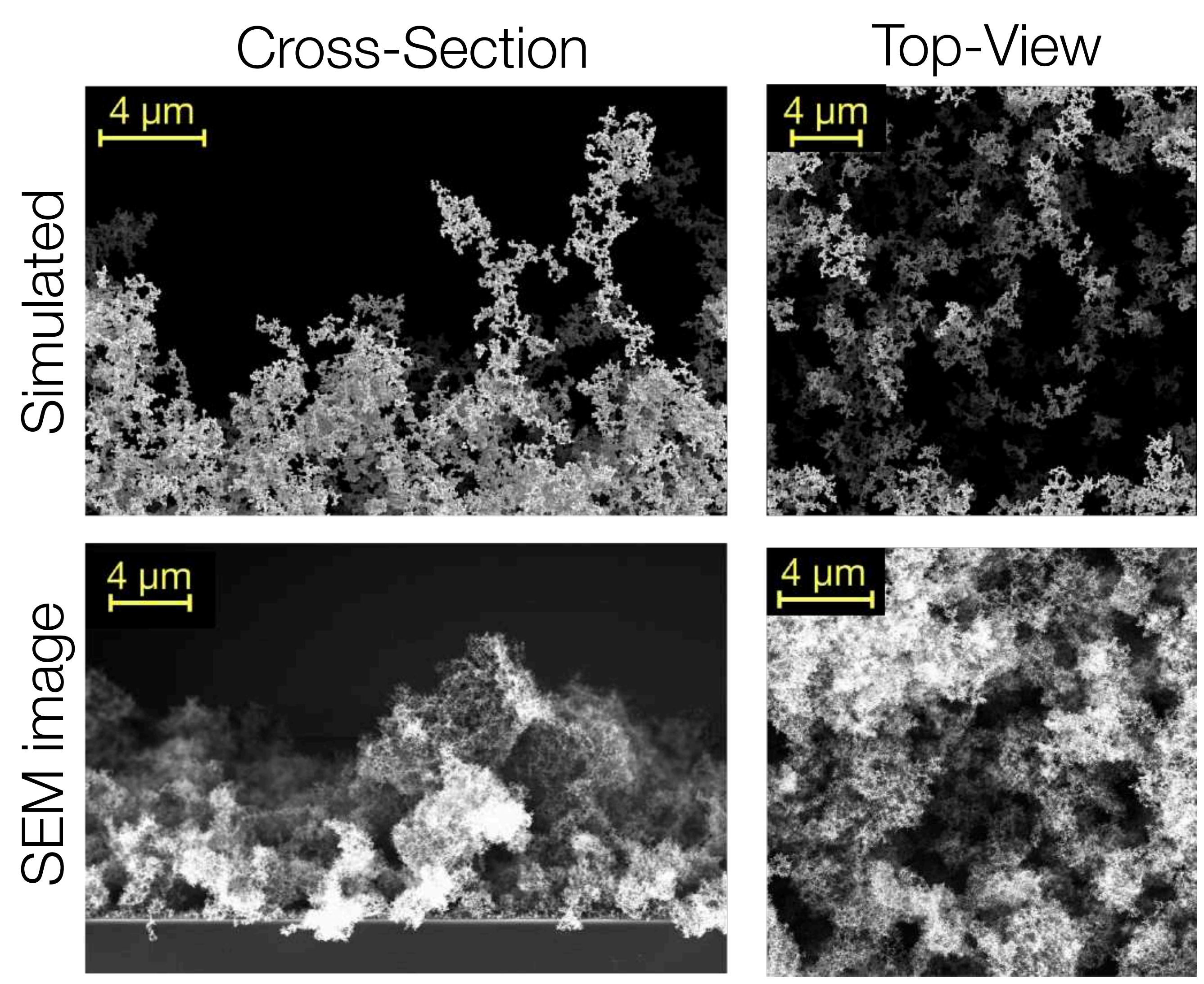


immagini boh **with the nanostructure**

The nanostructure is obtained via a cluster-cluster aggregation model that mimics the foam growth



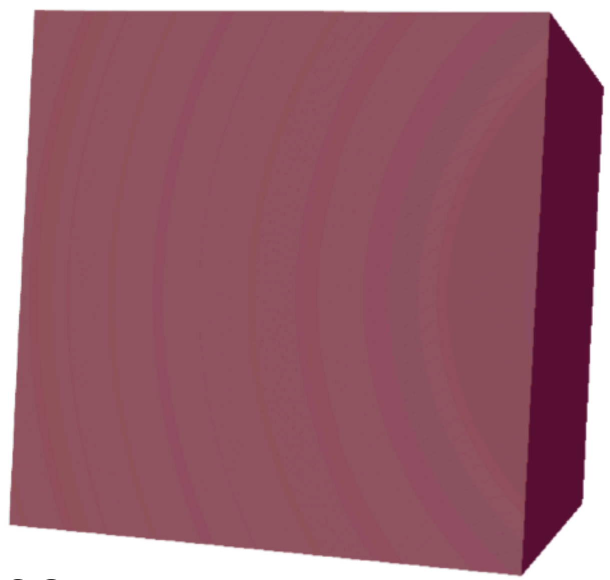
model vs. real

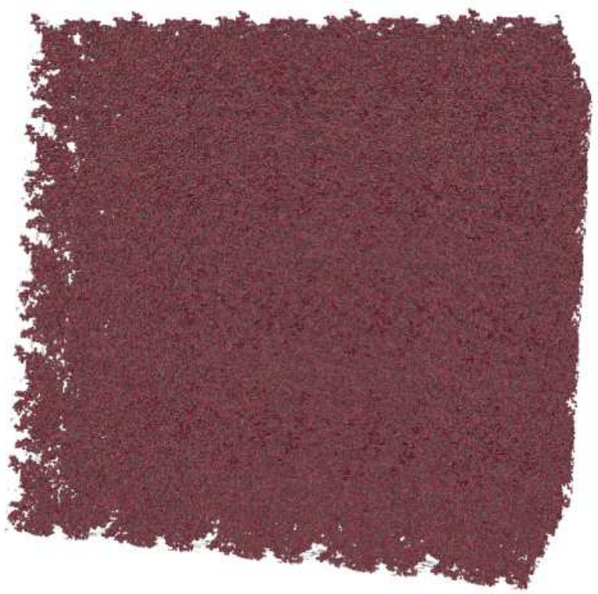


3D PIC simulations to asses the influence of the nanostructure in the physical processes at play

homogeneous plasma | **foam-like plasma**

without substrate



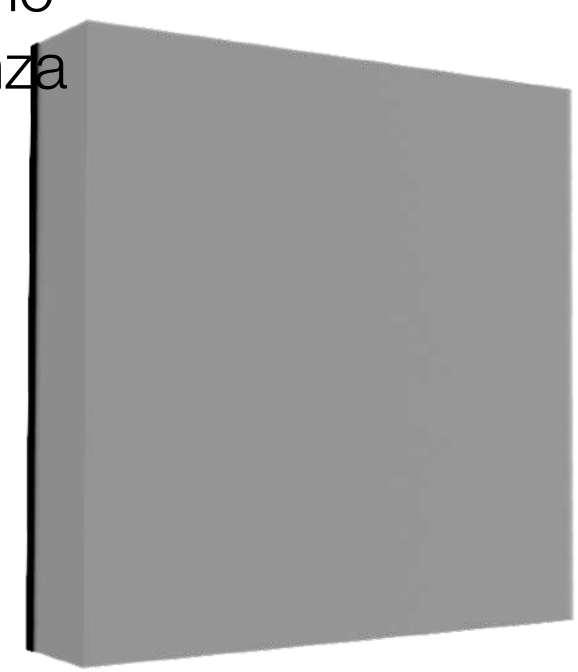


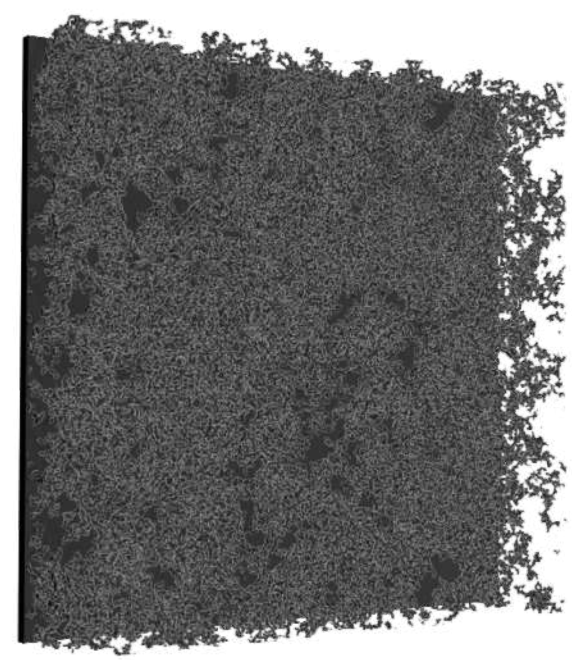
a0 = 5,15,45
ne = 3nc
sphere density 60nc
raggio
CHECK DENSITY

w = 5 lambd
t = 30 fs
P pol

notare che siamo vicino
alla soglia di trasparenza

with substrate





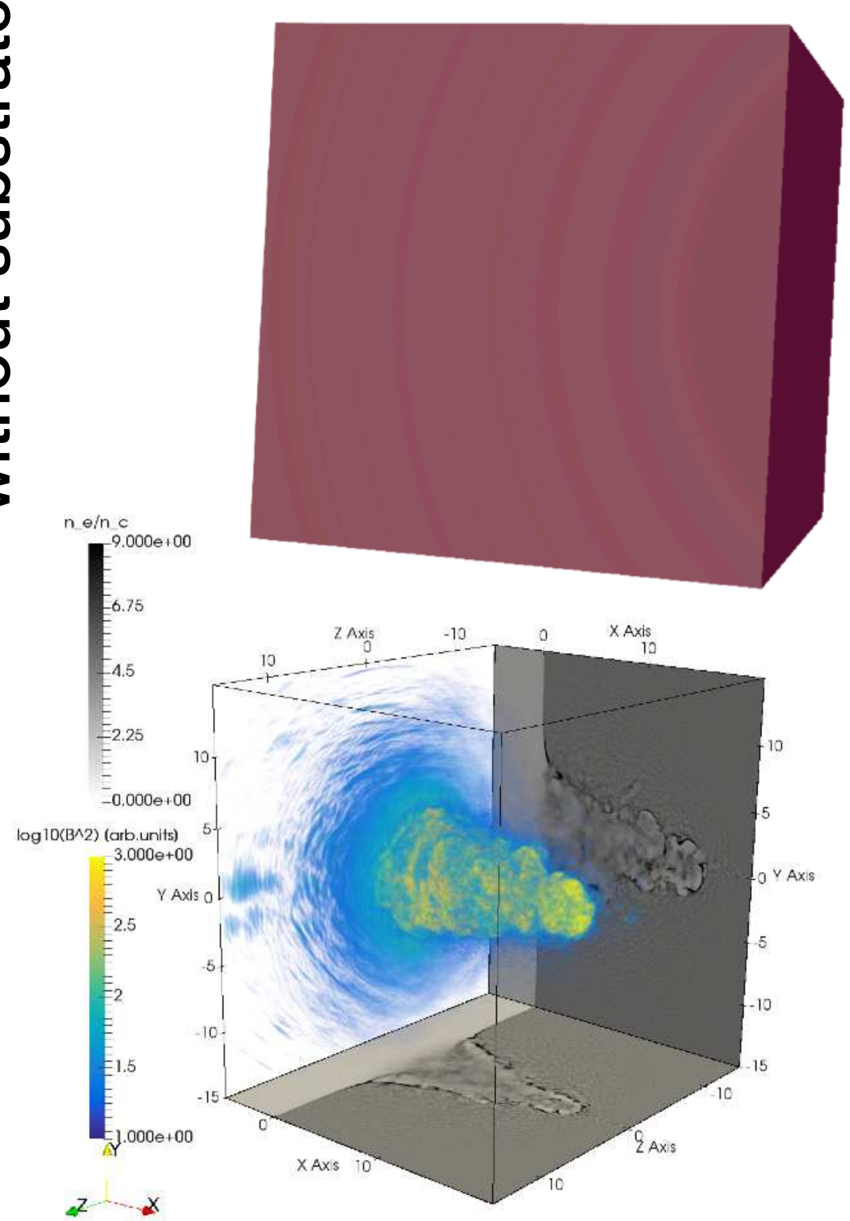
a0 = 4
ne = 2.29 nc
4 lambda thick
sphere density
raggio

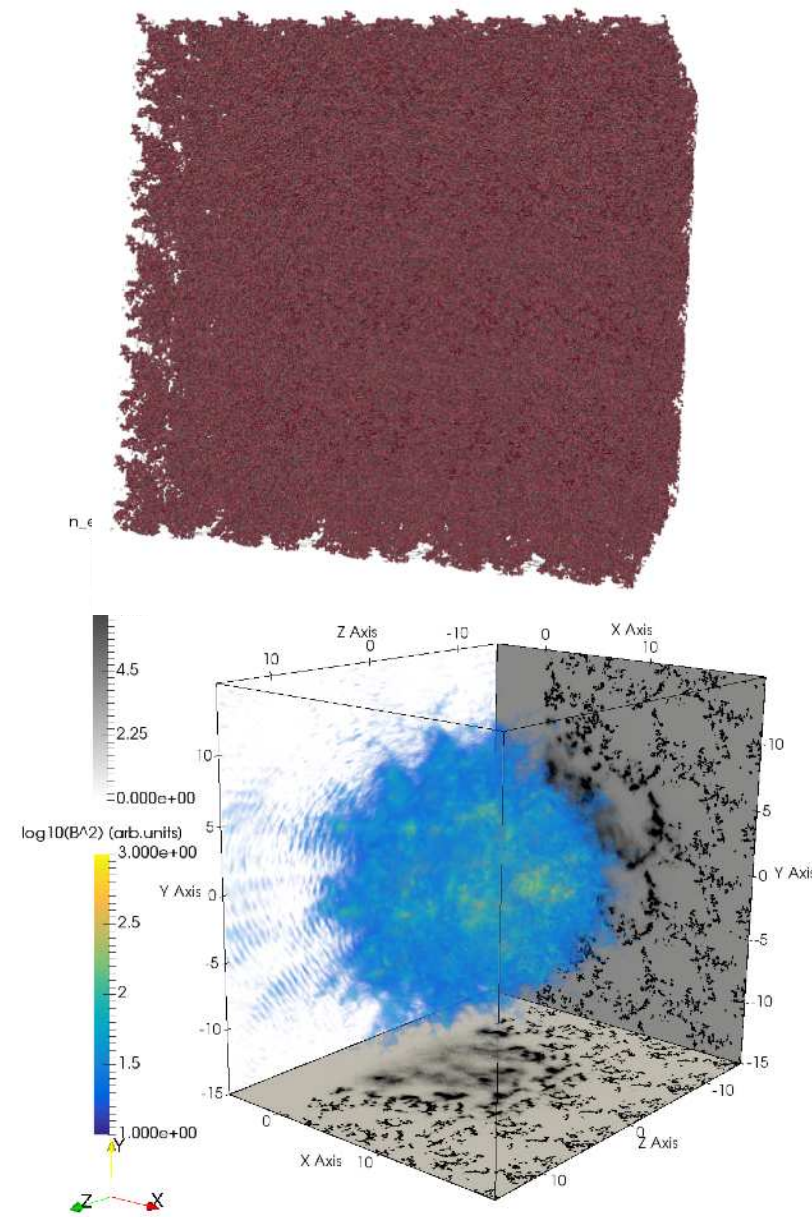
Già la propagazione viene modificata

homogeneous plasma

foam-like plasma

without substrate



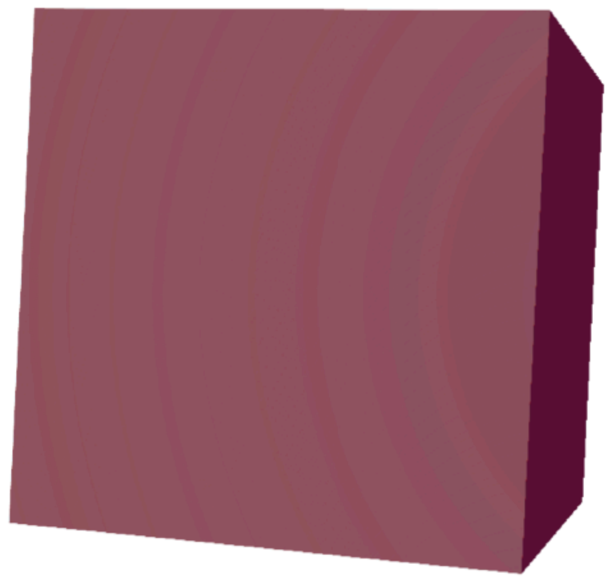


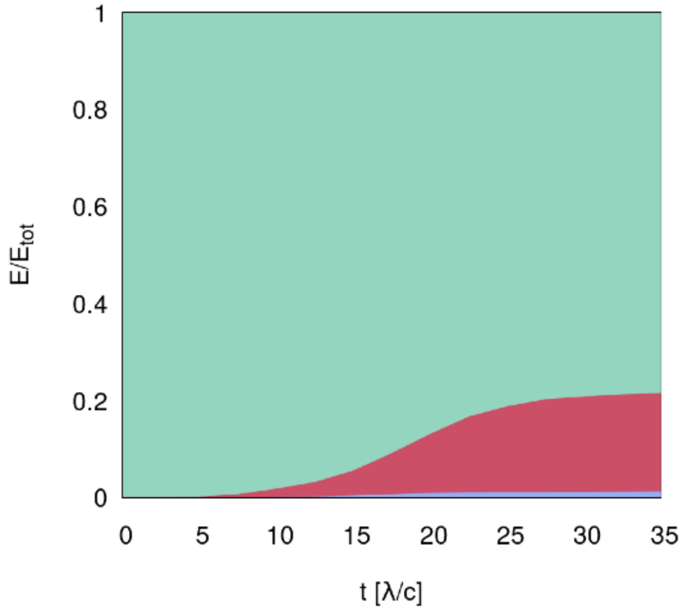
a0 = 45
ne = 3nc

Assorbimento boom con nano: sia elettroni che ioni, ma se prima gli ioni non assorbivano un tubo adesso tanto

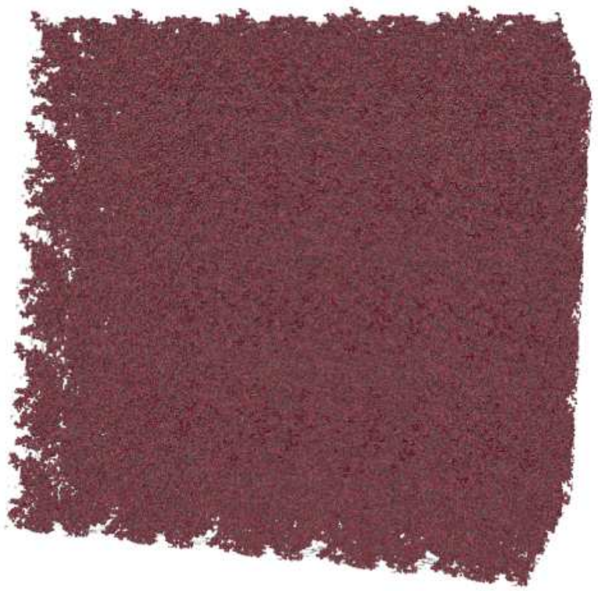
without substrate

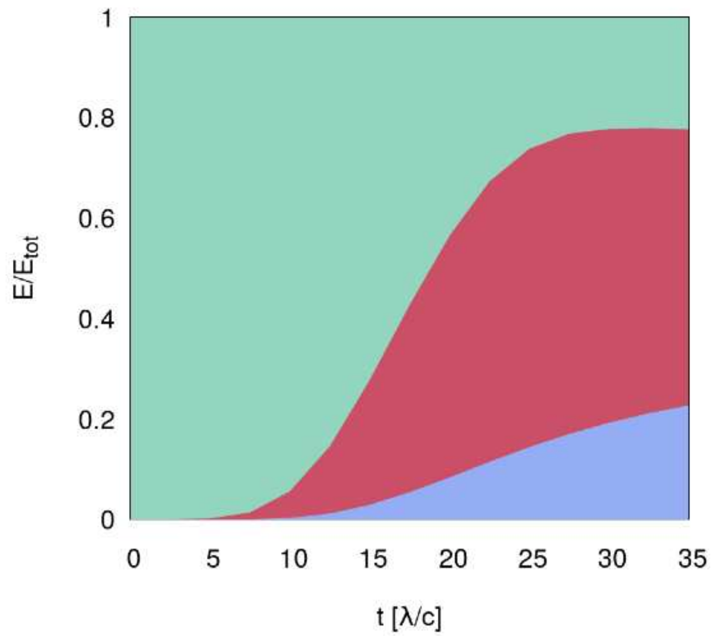
homogeneous plasma





foam-like plasma





a0 = 5

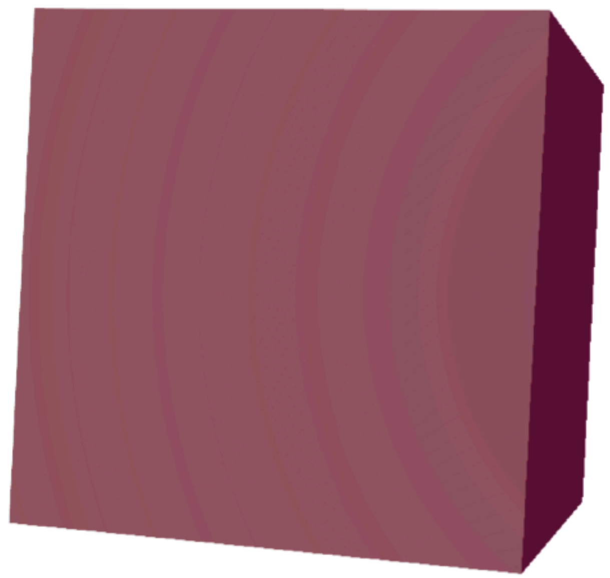
ne = 3nc

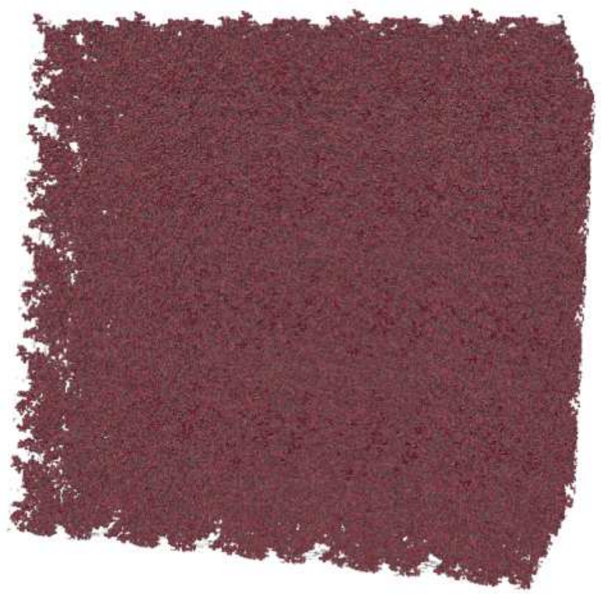
Lo interpretiamo con esplosione degli aggregati di nanoparticelle

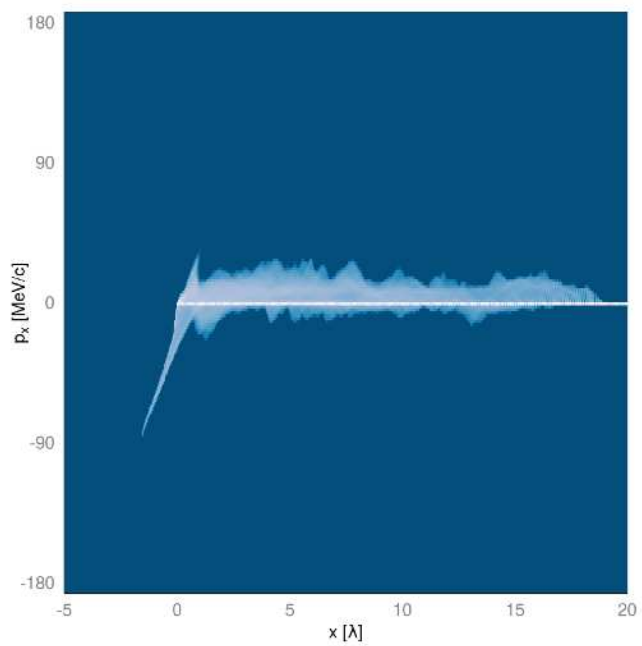
homogeneous plasma

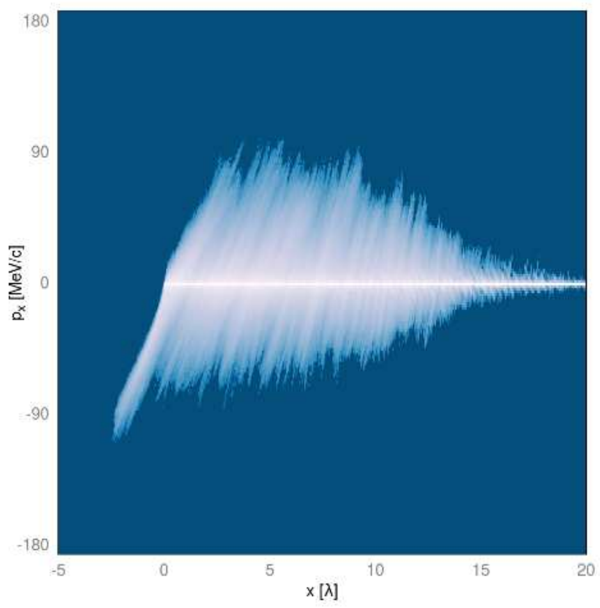
foam-like plasma

without substrate









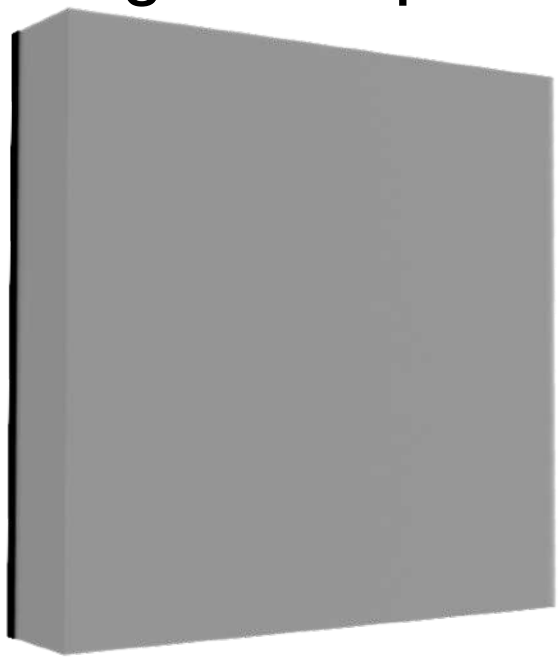
a0 = 15
ne = 3nc

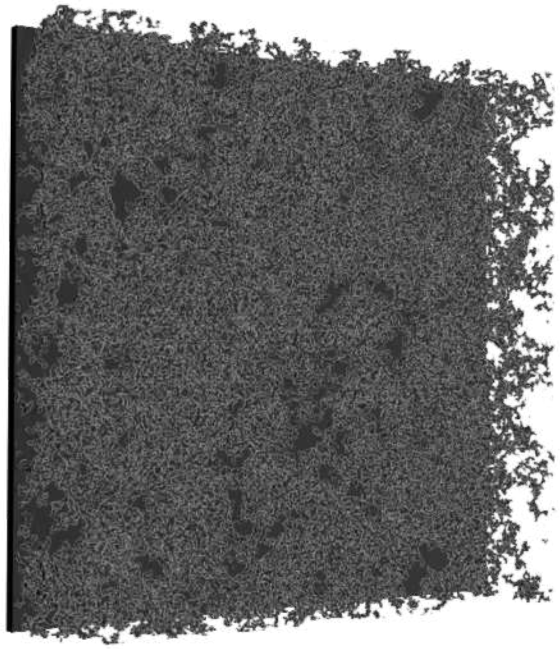
Abbiamo anche iniziato a esplorare l'accelerazione e dai primi risultati si vede una differenza significativa

homogeneous plasma

foam-like plasma

with substrate

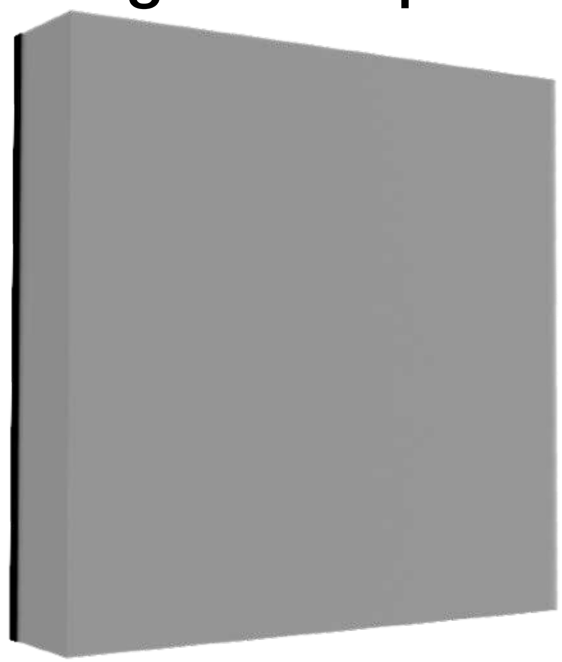




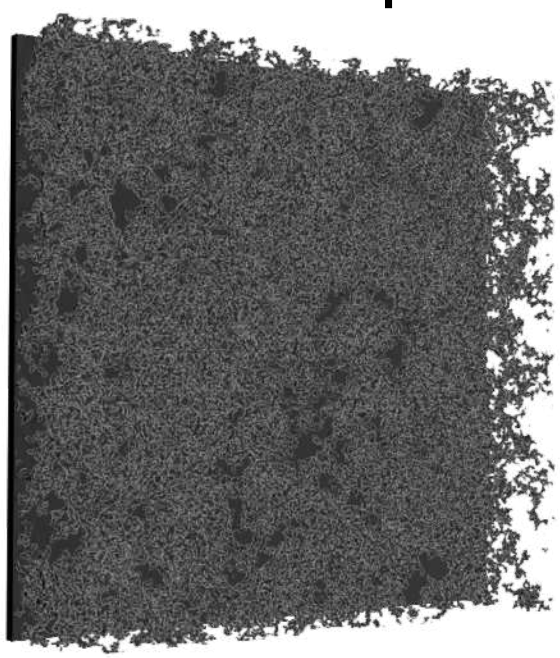
Assorbimenti

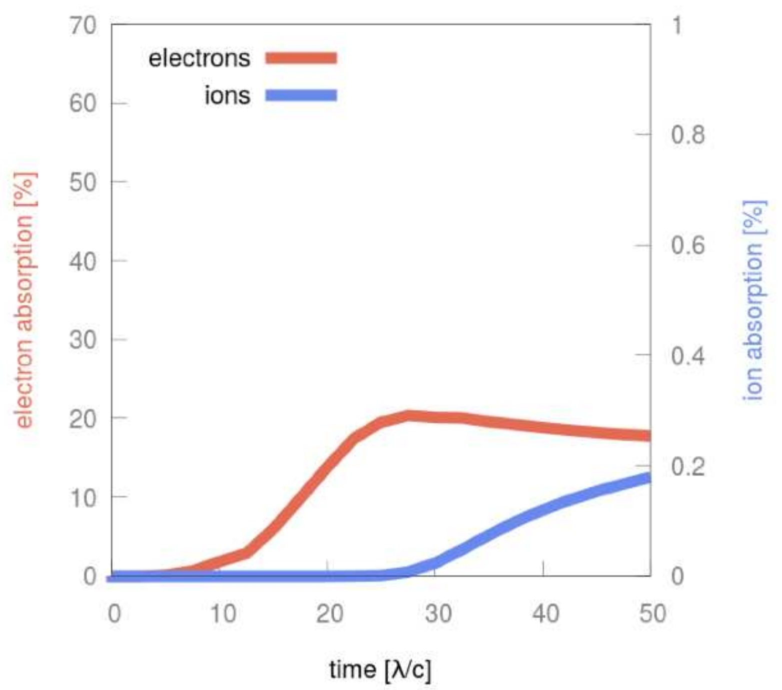
with substrate

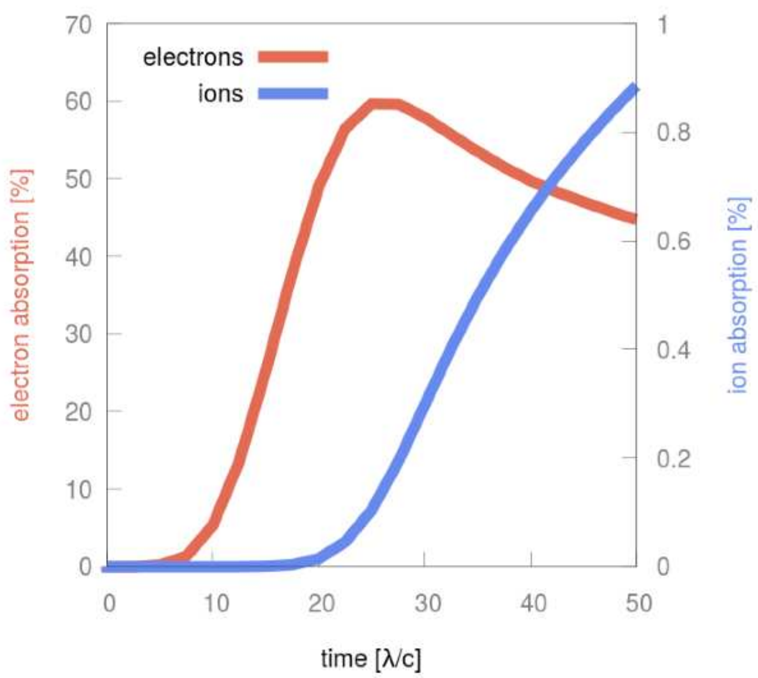
homogeneous plasma



foam-like plasma





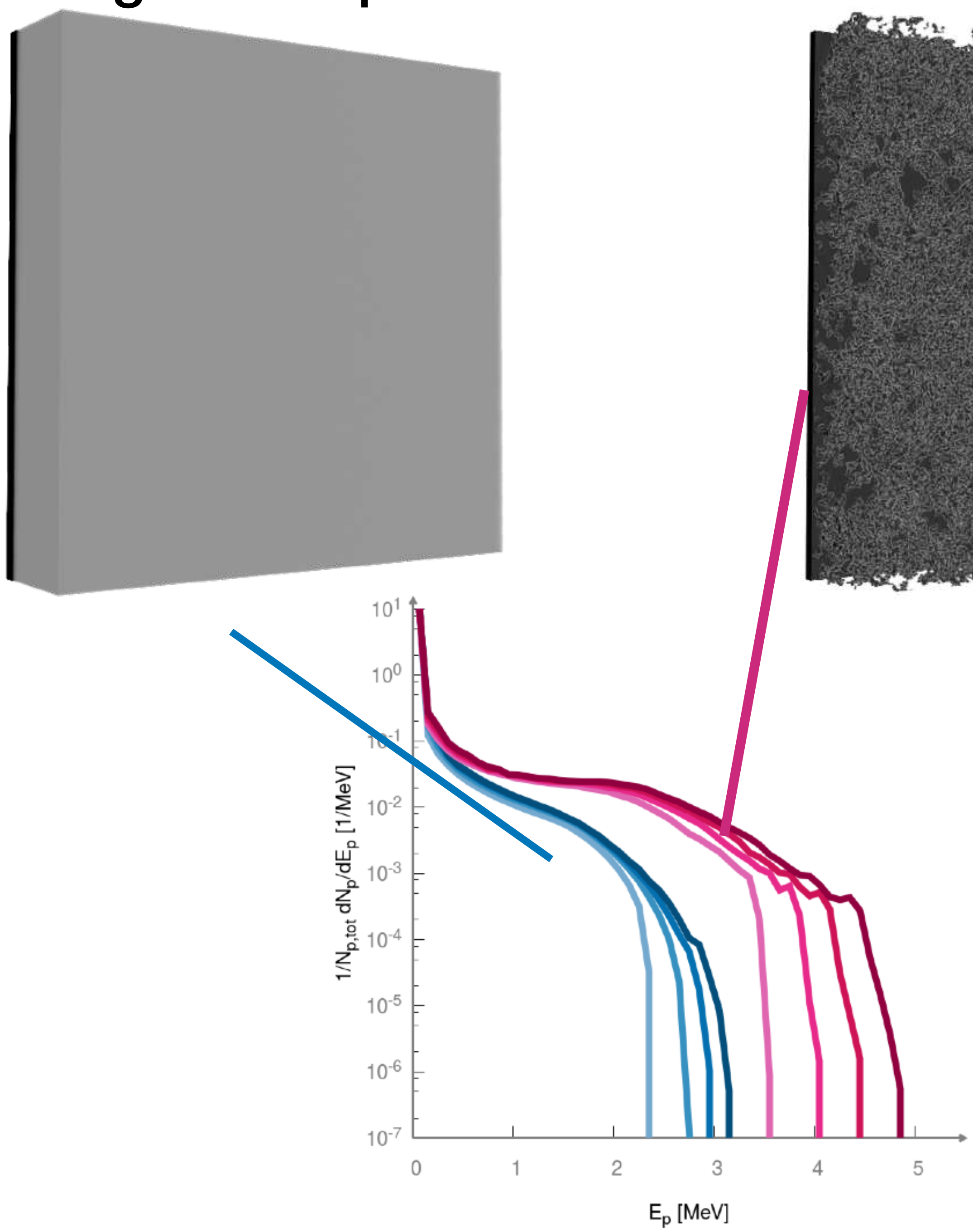


Spettrioni

homogeneous plasma

foam-like plasma

with substrate

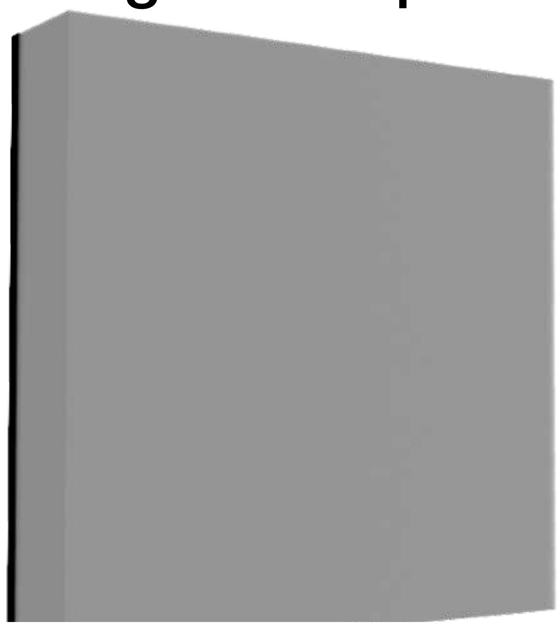


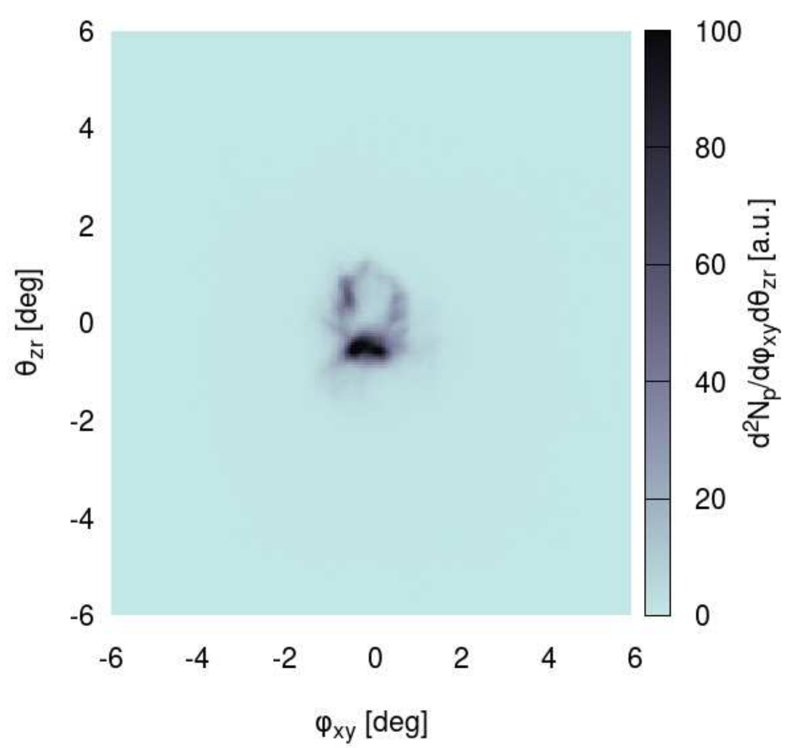
RCF

più collimati con un plasma pulito
con nano ci sono degli spot non esattamente a 0 gradi

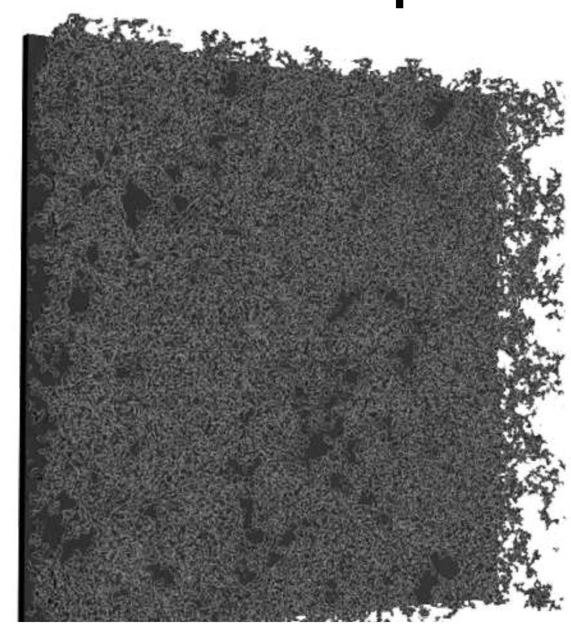
with substrate

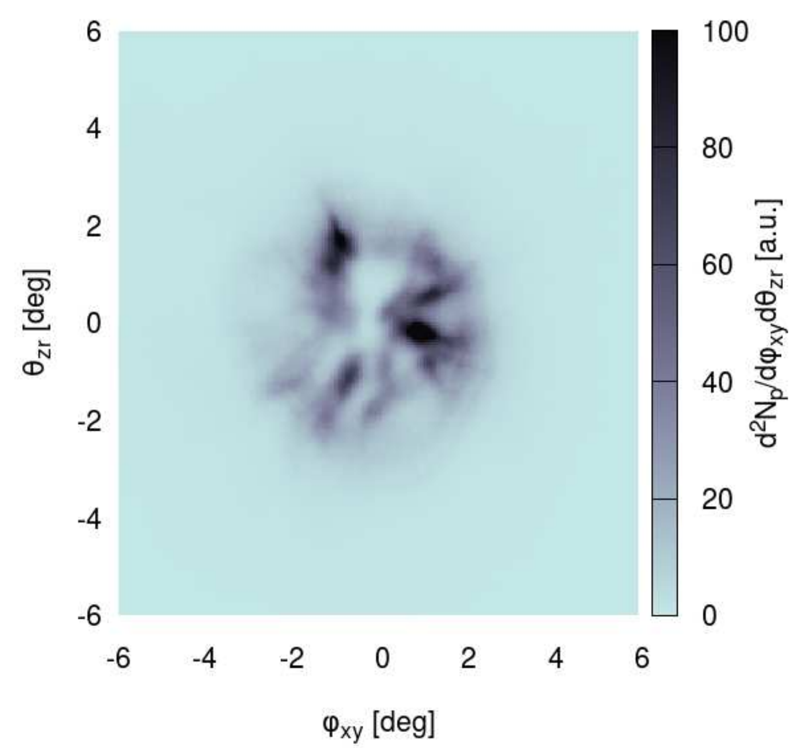
homogeneous plasma





foam-like plasma





Applications: exploit the enhancement to enable applications given a ~10TW laser system

PIXE

NEUTRONS

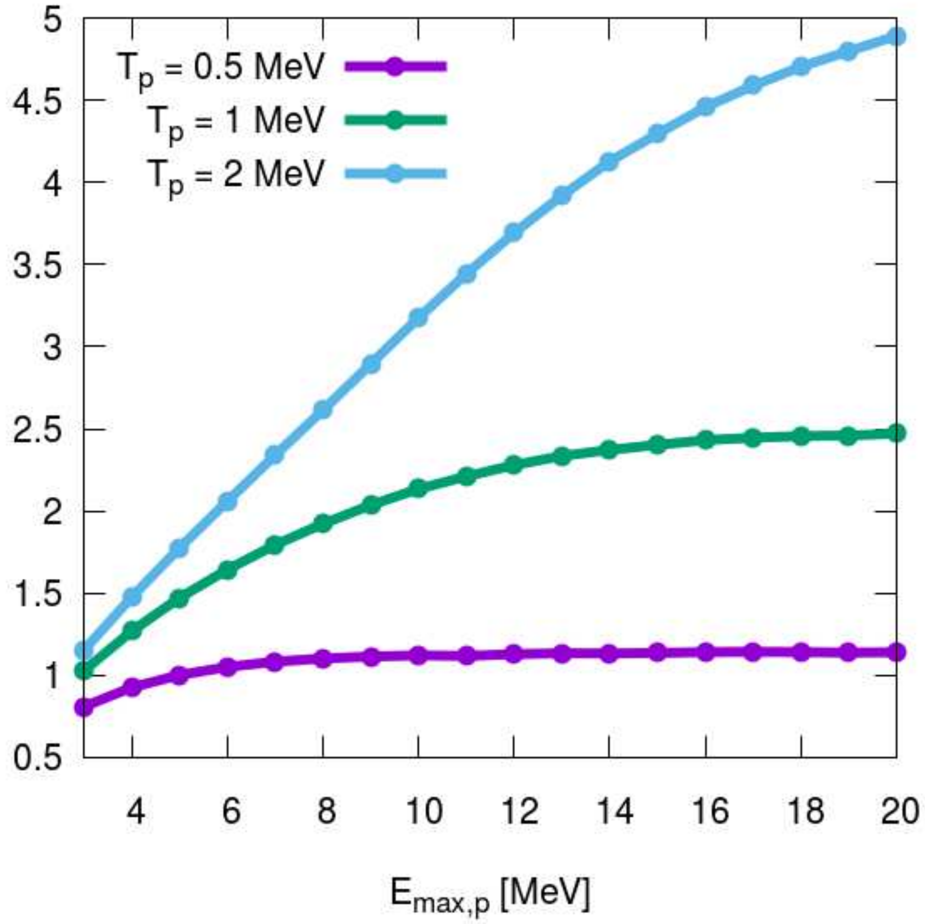
design of experimental setup

Application in materials science: Proton-Induced X-ray Emission (PIXE)

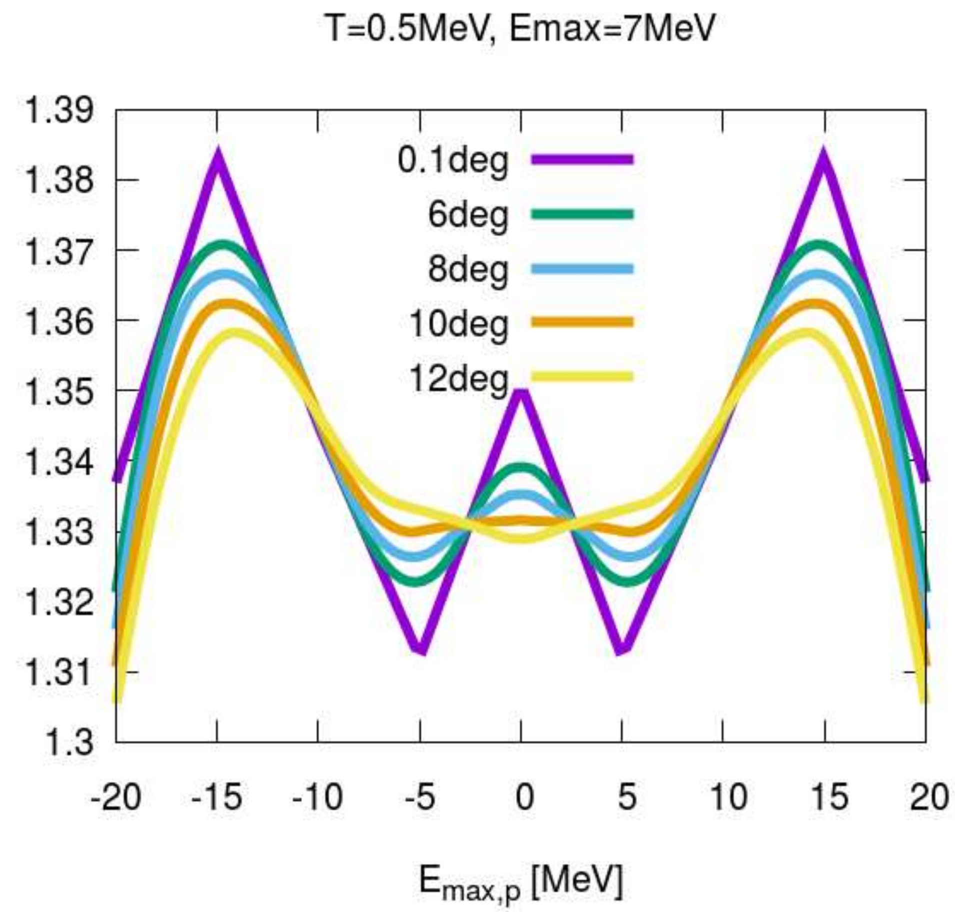
immagine complessiva di luca
solo menzione rapida alle questioni challenging
e al fatto che spettro exp può non essere male

Application in nuclear engineering: compact laser-driven neutron sources

Li per adesso ma ci sono questioni da considerare



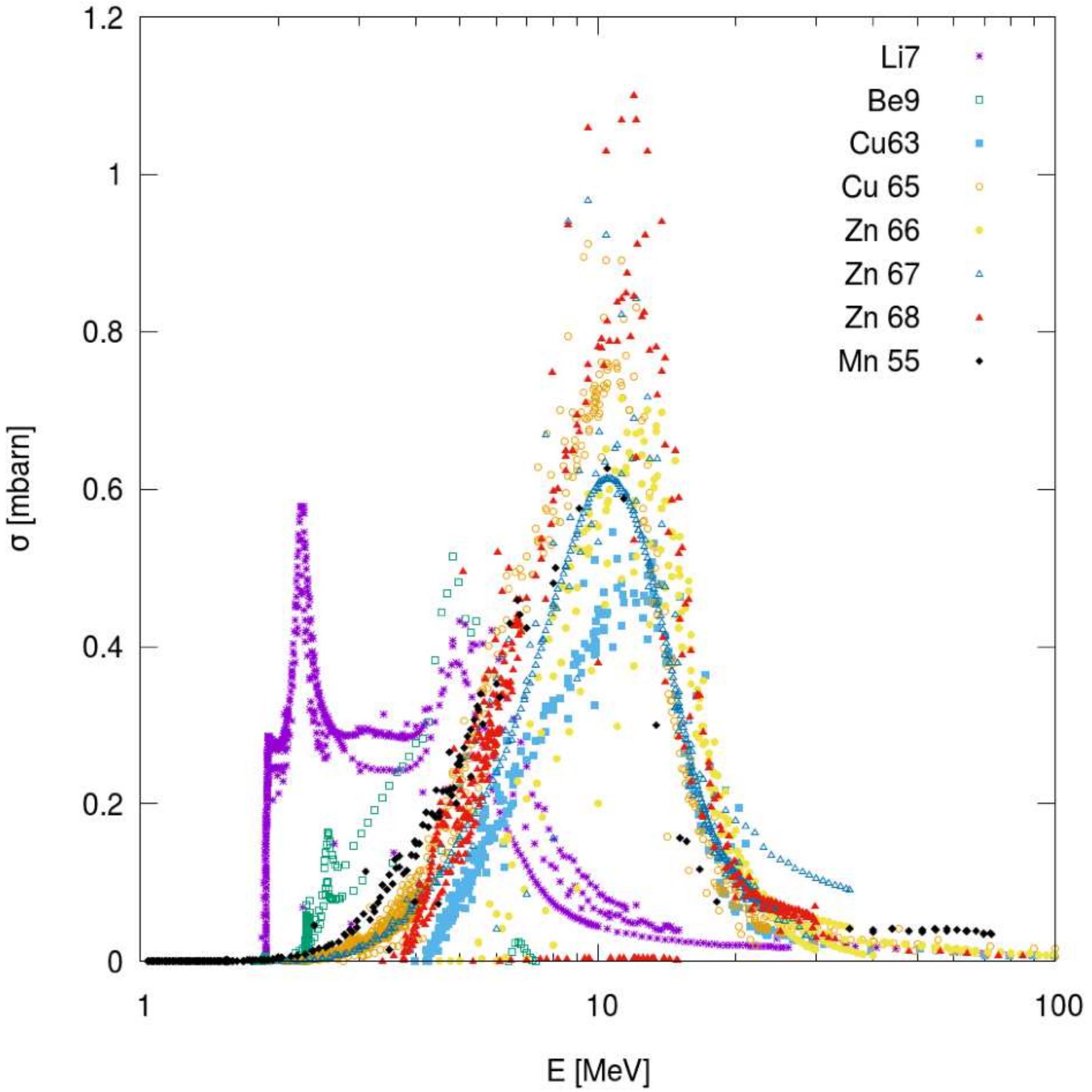
con energie moderate degli ioni (T=0.5, Max=7MeV (come il nostro PIC) si ha 1e-4 di conversione p->n)



CHECK DI QUESTO GRAFICO
SE è GIUSTO PERò FORSE SI Può DIRE CHE LA DIPENDENZA DALLA DIVERGENZA DEI PROT NON è GRANDE

Ottimizzazione del convertitore: questioni

cross section pn



cross section scattering

QUESTIONI SU MATERIALI A MEDIO Z:
POSSONO AIUTARE A SFRUTTARE PROTONI
A Pù ALTA
ENERGIA MA NON BANALE

SPESSORE <-> RISCALDAMENTO
SPESSORE <-> COLLIMAZIONE/ ENERGIA NEU

Application in nuclear engineering: compact laser-driven neutron sources

assess the feasibility

+

design of a compact source

piccante

Open Source PIC Code

GEANT4

A SIMULATION TOOLKIT

Summary + conclusioni

la nano bisogna tenerla in conto per fare simulazioni con pretese realistiche

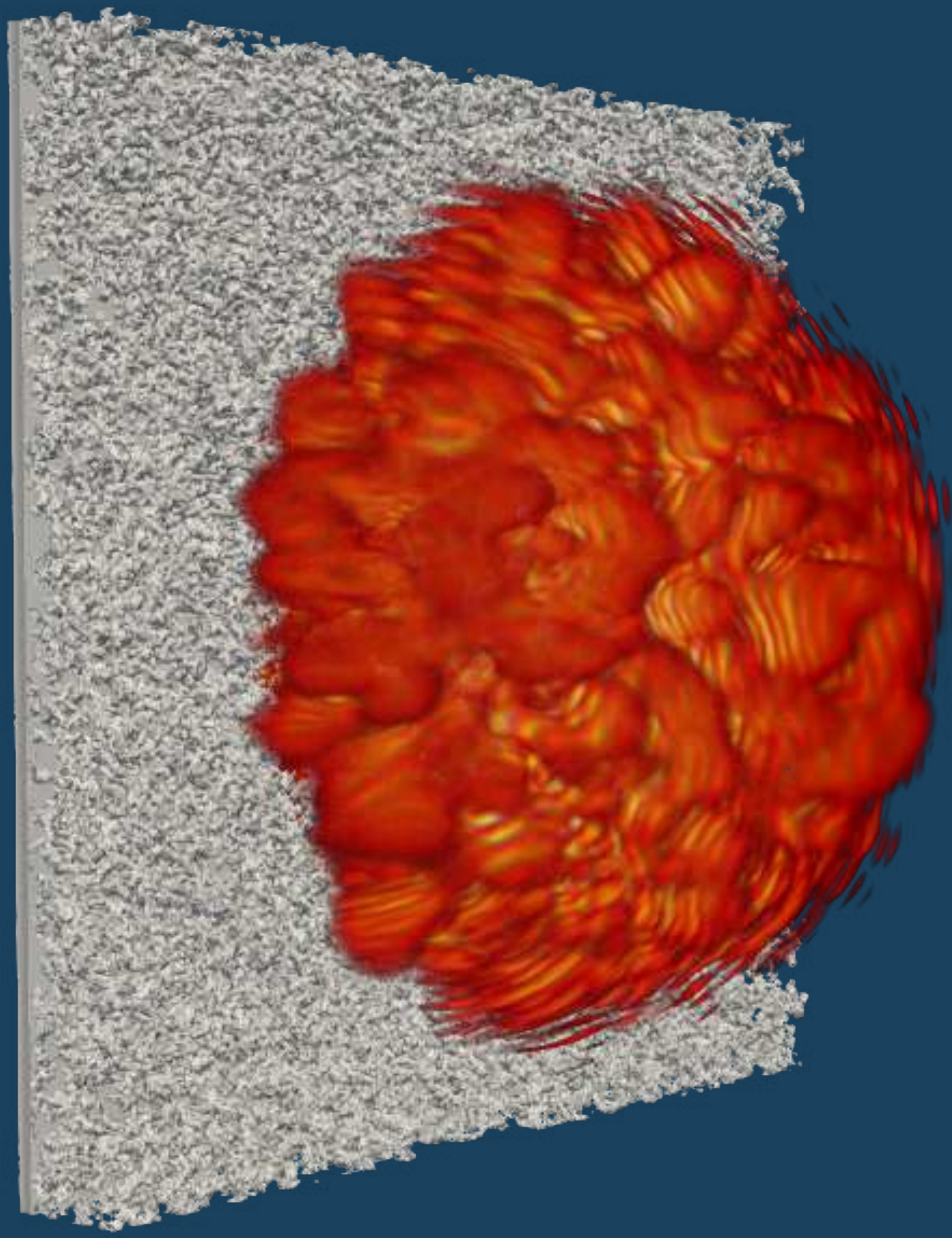
STIAMO LAVORANDO VERSO LE APPLICAZIONI
"COMPATTE" E SEMBRA PROMETTENTE

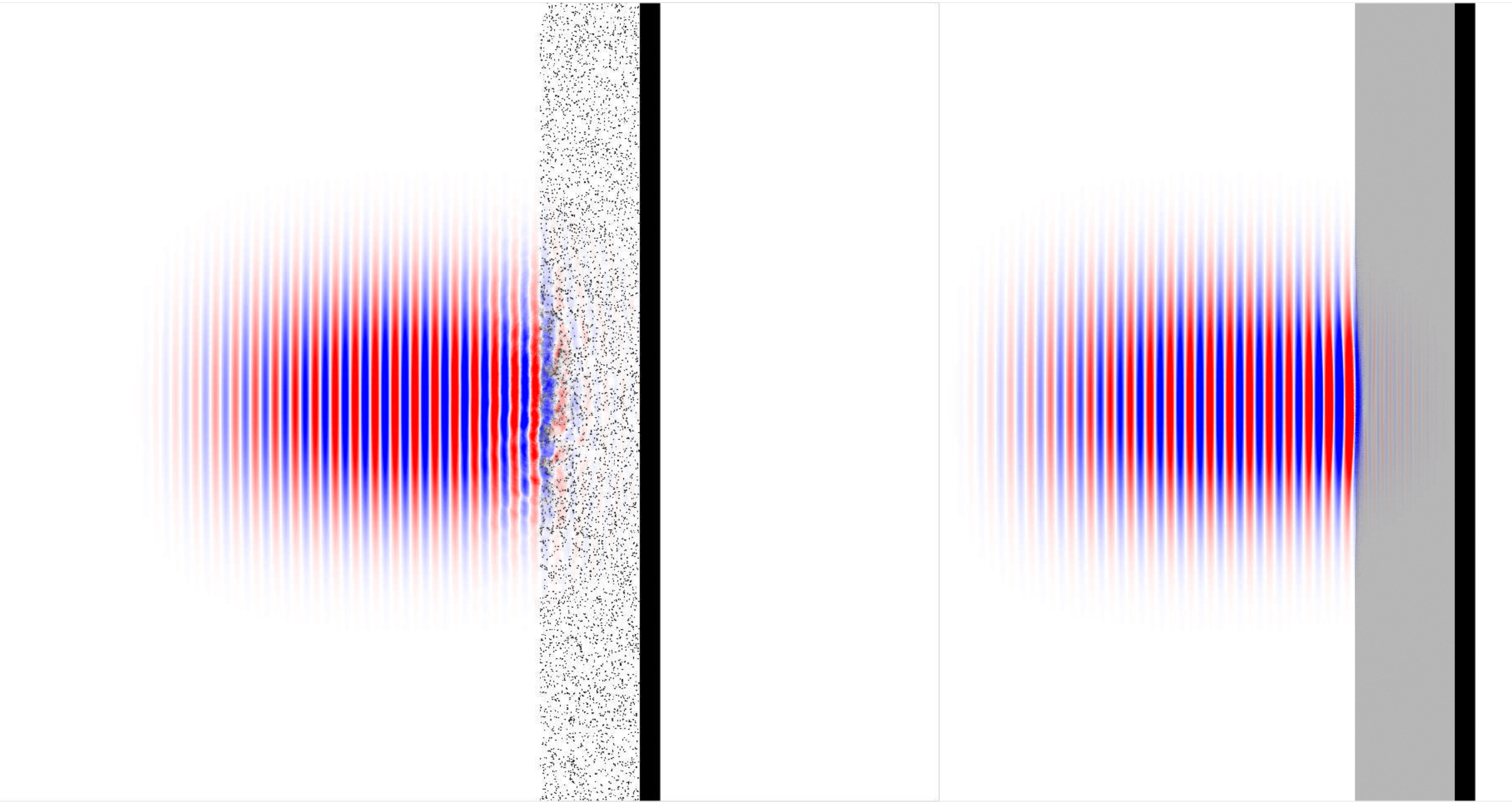
THE END
THANK YOU!

arianna.formenti@polimi.it

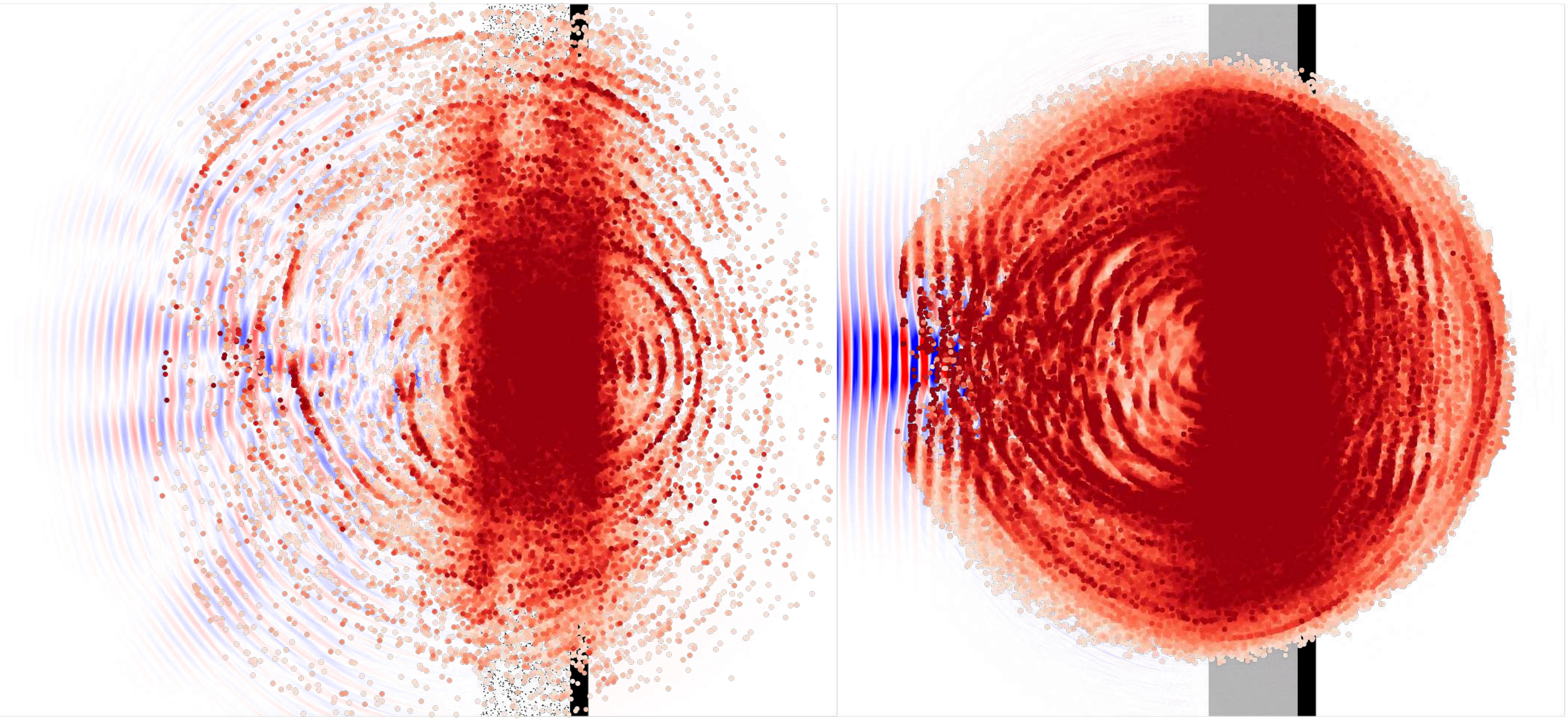
www.ensure.polimi.it

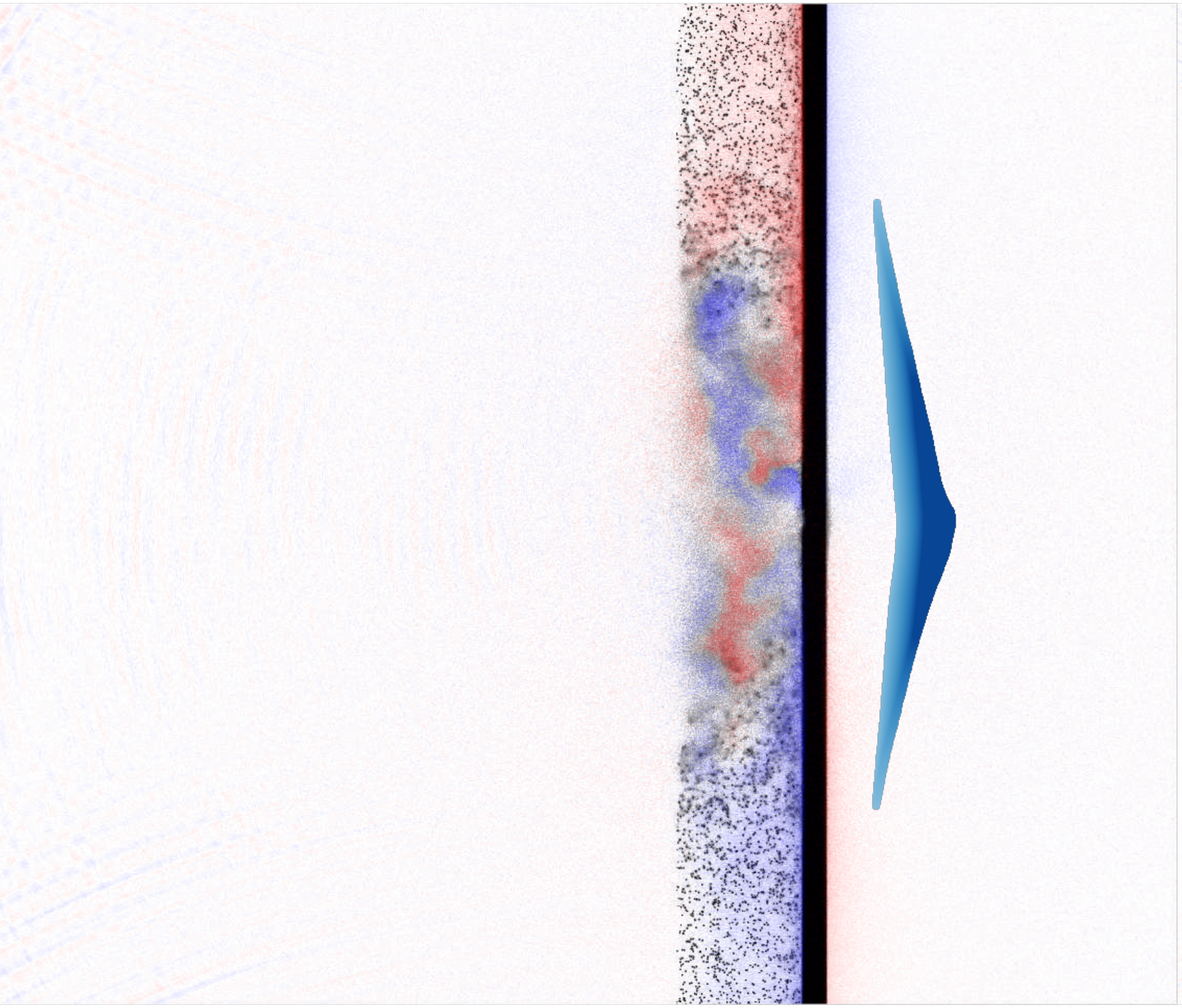
www.nanolab.polimi.it

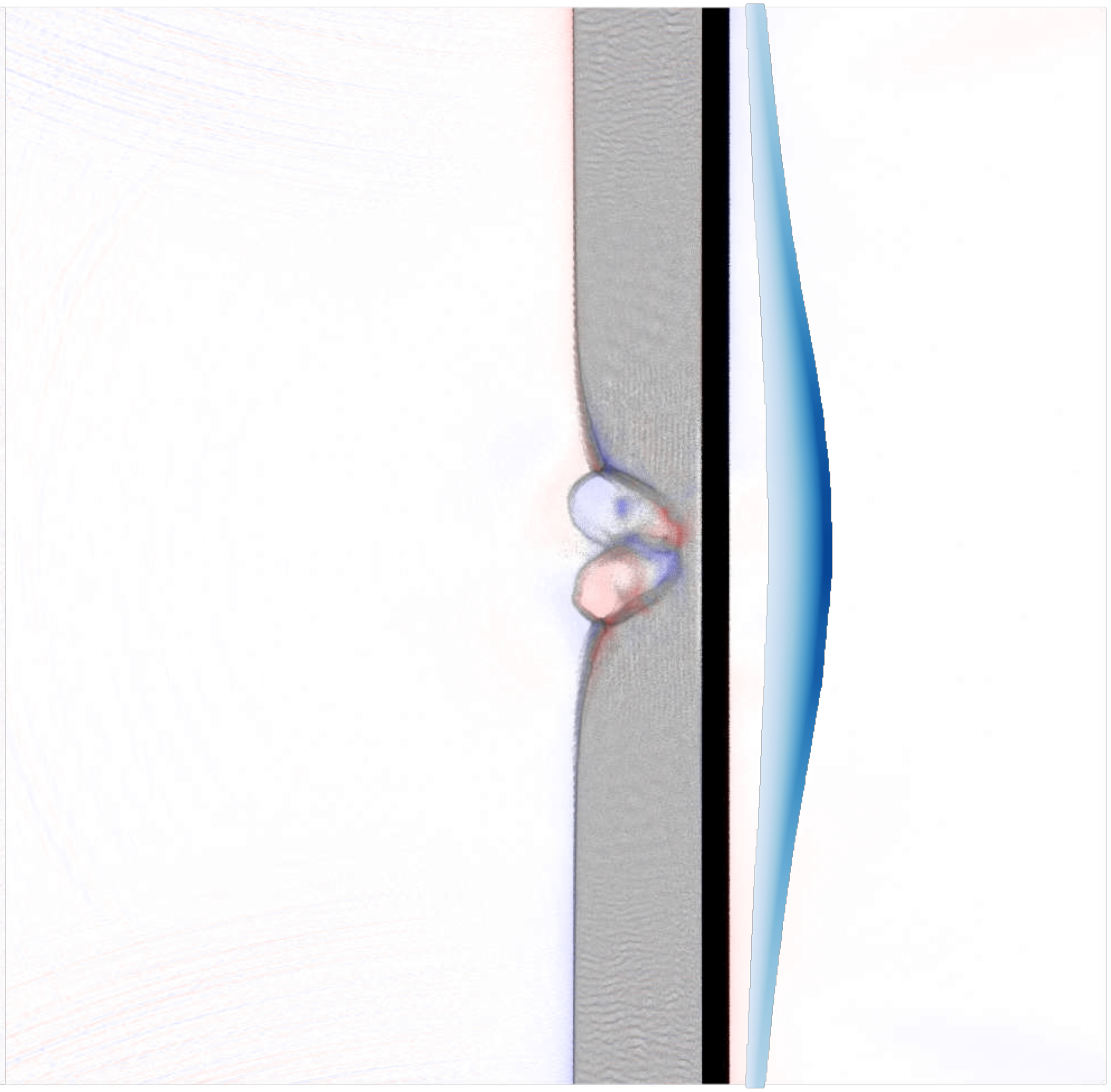


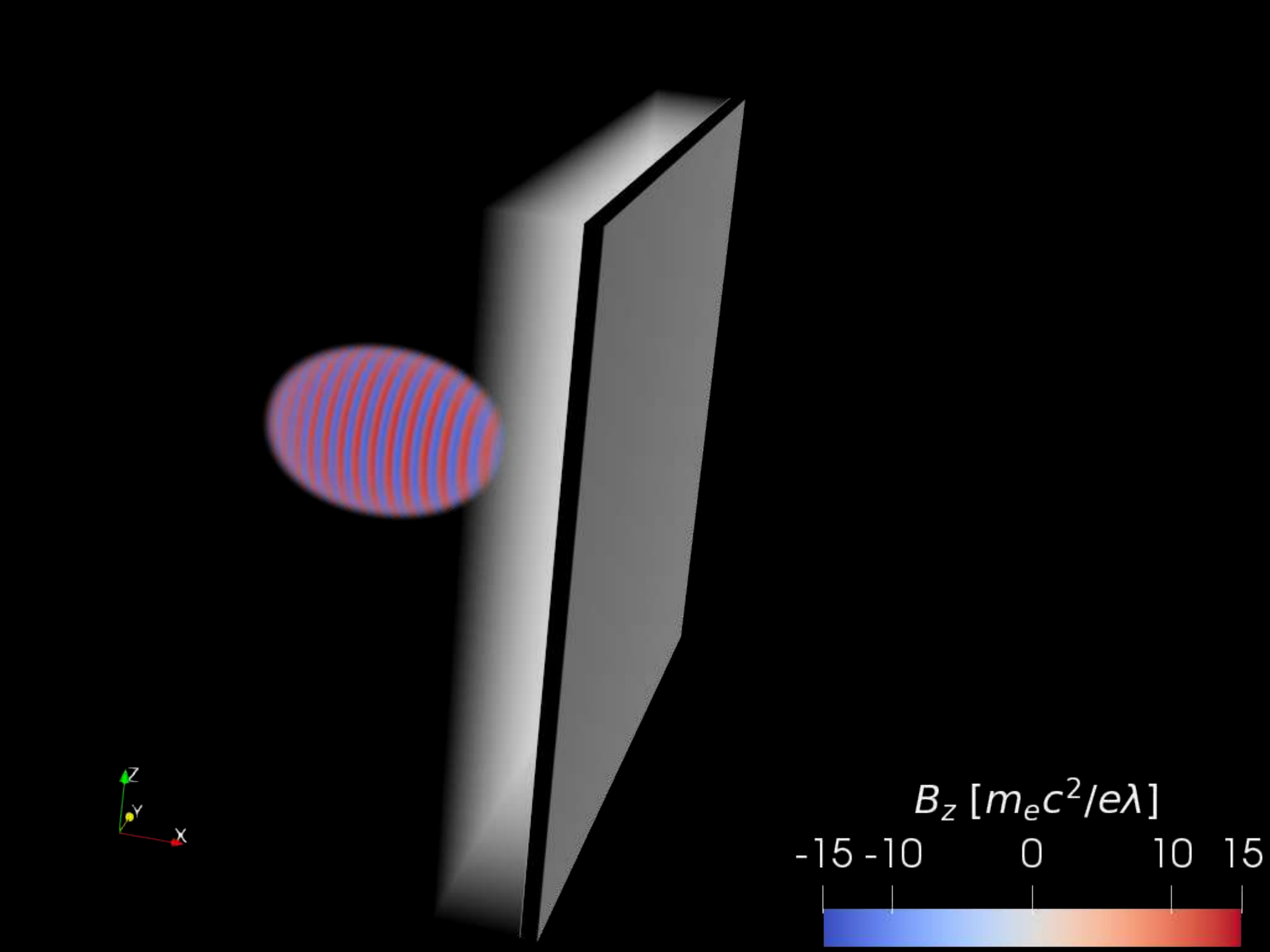


maybe its the density that changes

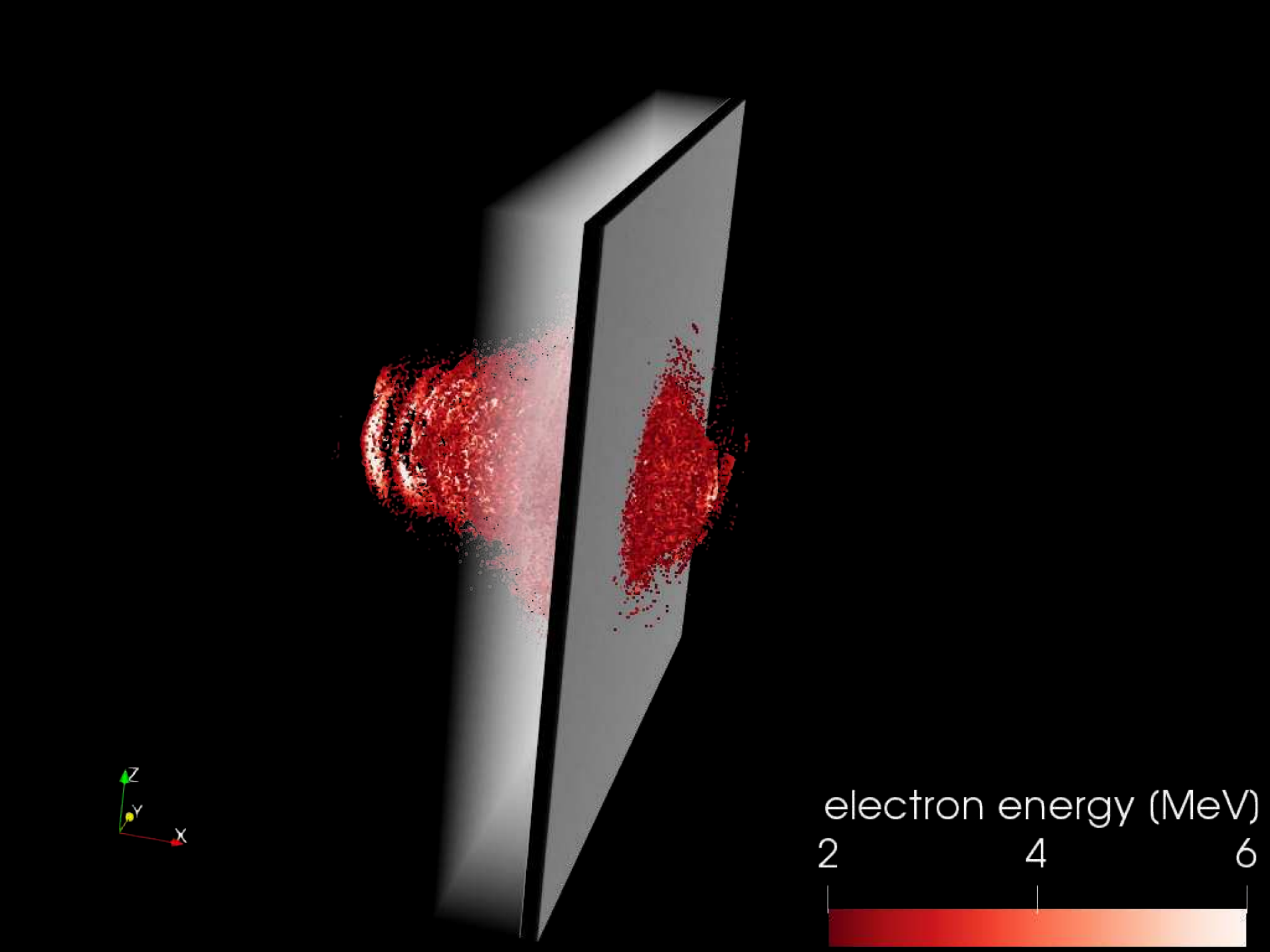


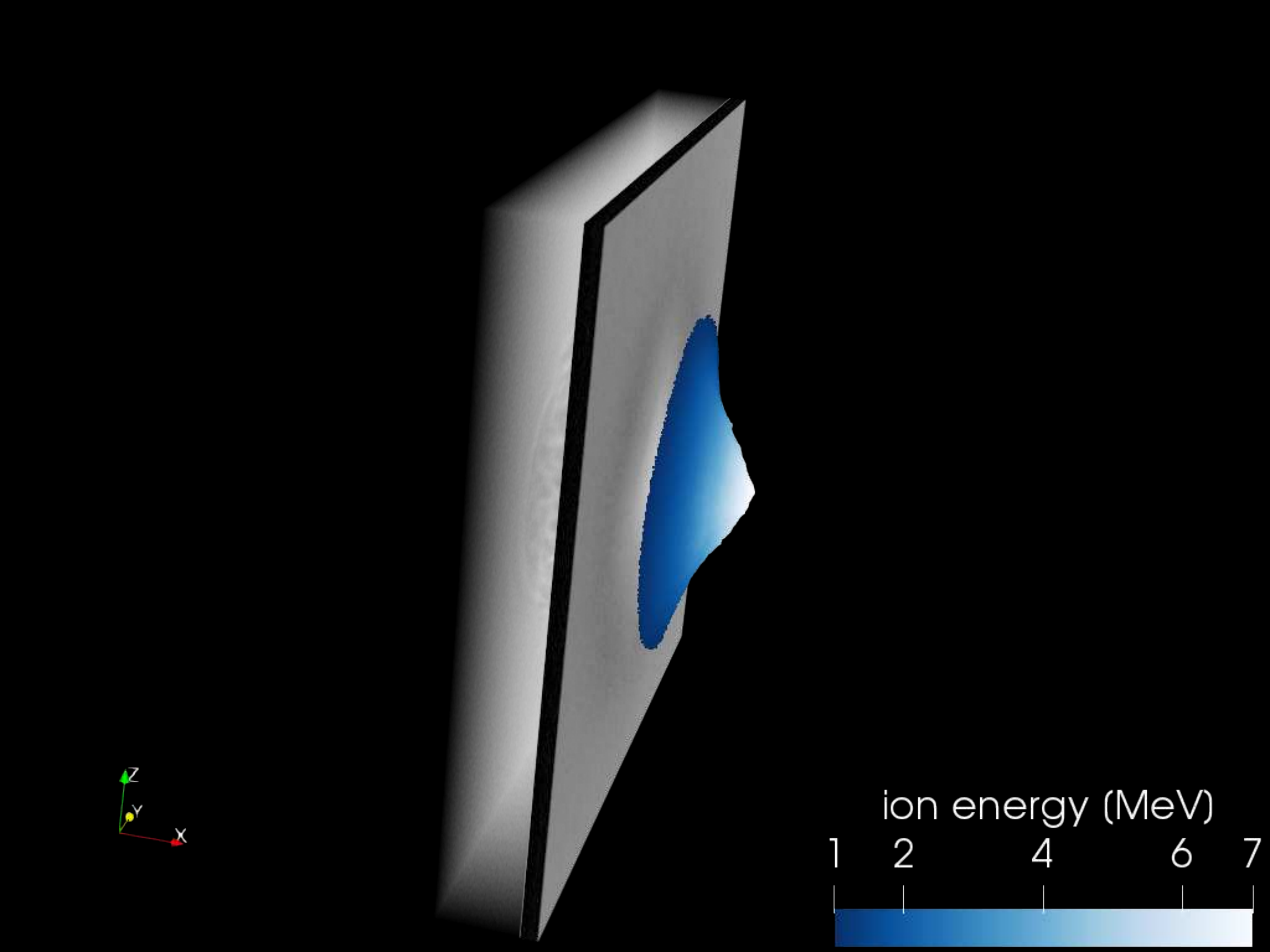




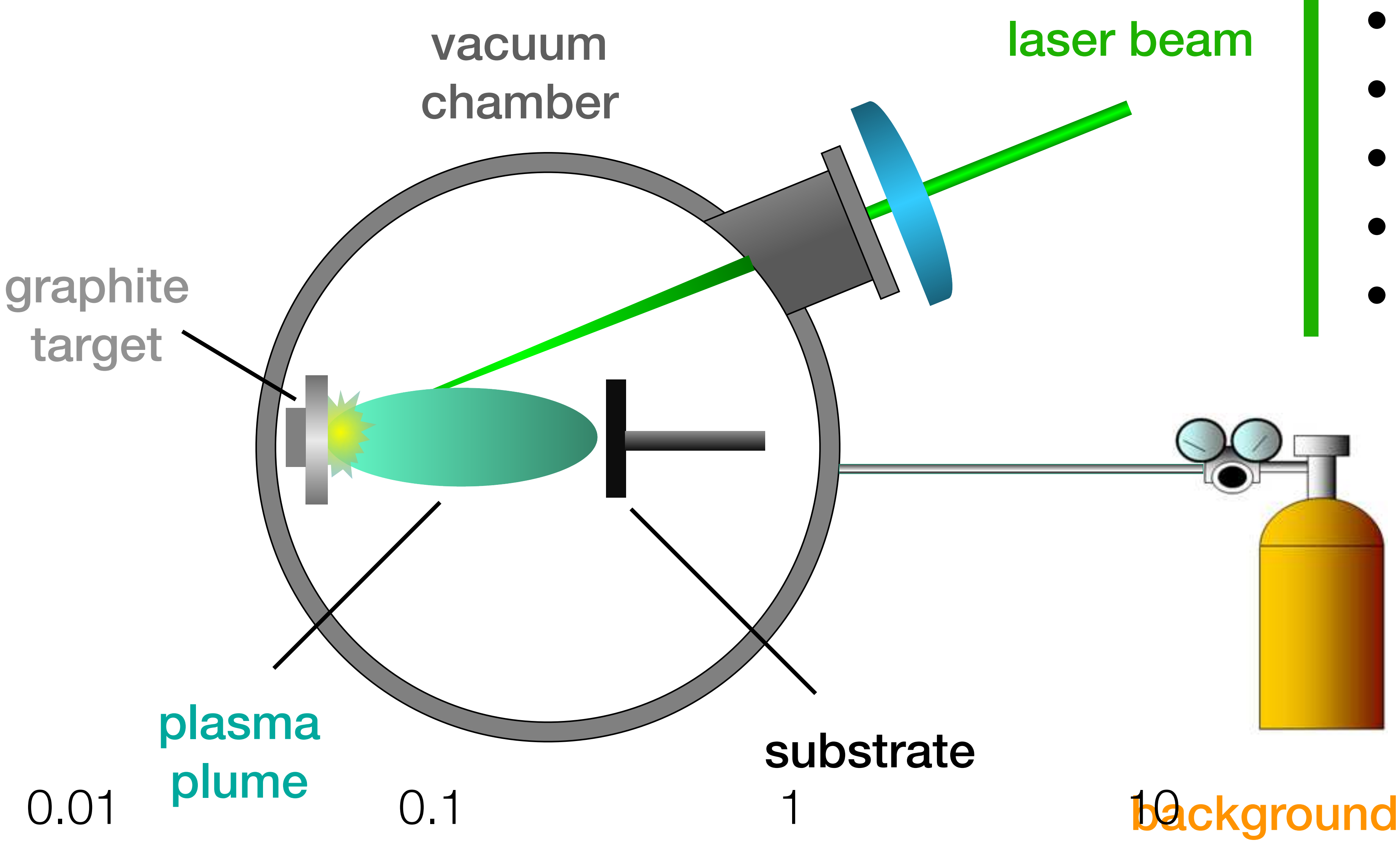


Z
Y
X
$B_z\ [m_e c^2/e\lambda]$
-15 -10 0 10 15


Z
Y
X
electron energy (MeV)
2
4
6


Z
Y
X
ion energy (MeV)
1
2
4
6
7

We produce carbon foams via the Pulsed Laser Deposition technique



- λ = 266, 532, 1064 nm
- τ = 7 ns
- E = 0.1 - 2 J
- RR = 10 Hz
- F = 0.1 - 20 J/cm^2
- I = 10^7 - 2 x 10^9 W/cm^2

- Inert (He, Ar…)
- Reactive (O_2)