POLITECNICO
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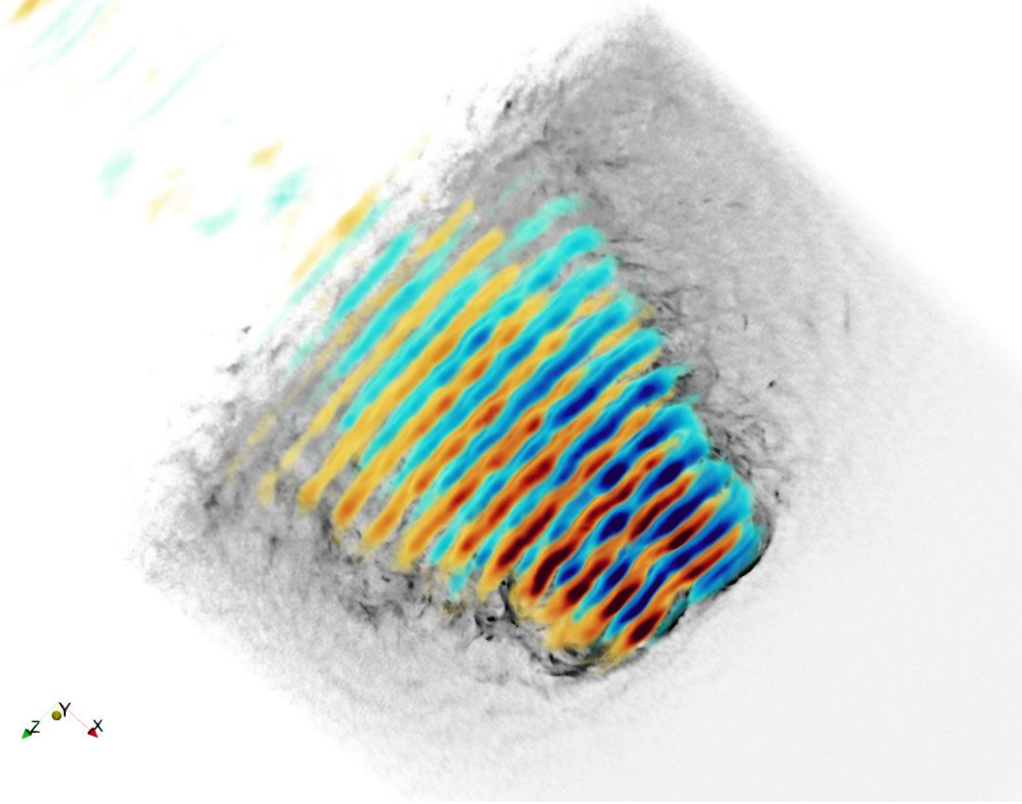
NanoLab

Department of Energy

ERC-2014-CoG No. 647554
ENSURE



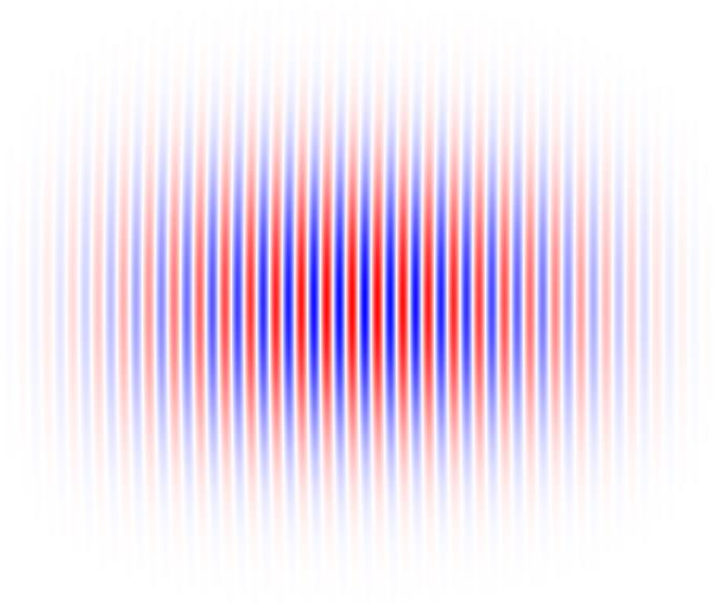
Investigation on near-critical targets for enhanced laser-driven ion acceleration

Andrea Pazzaglia

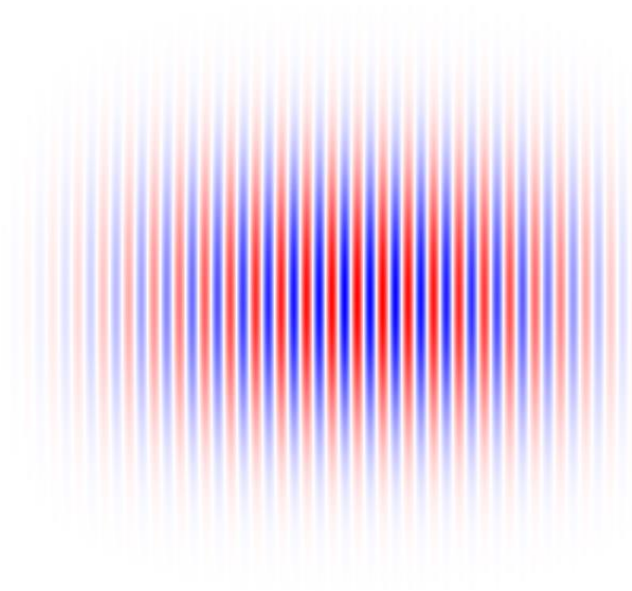
Department of Energy, Politecnico di Milano, Italy

Target Normal Sheath Acceleration (TNSA)

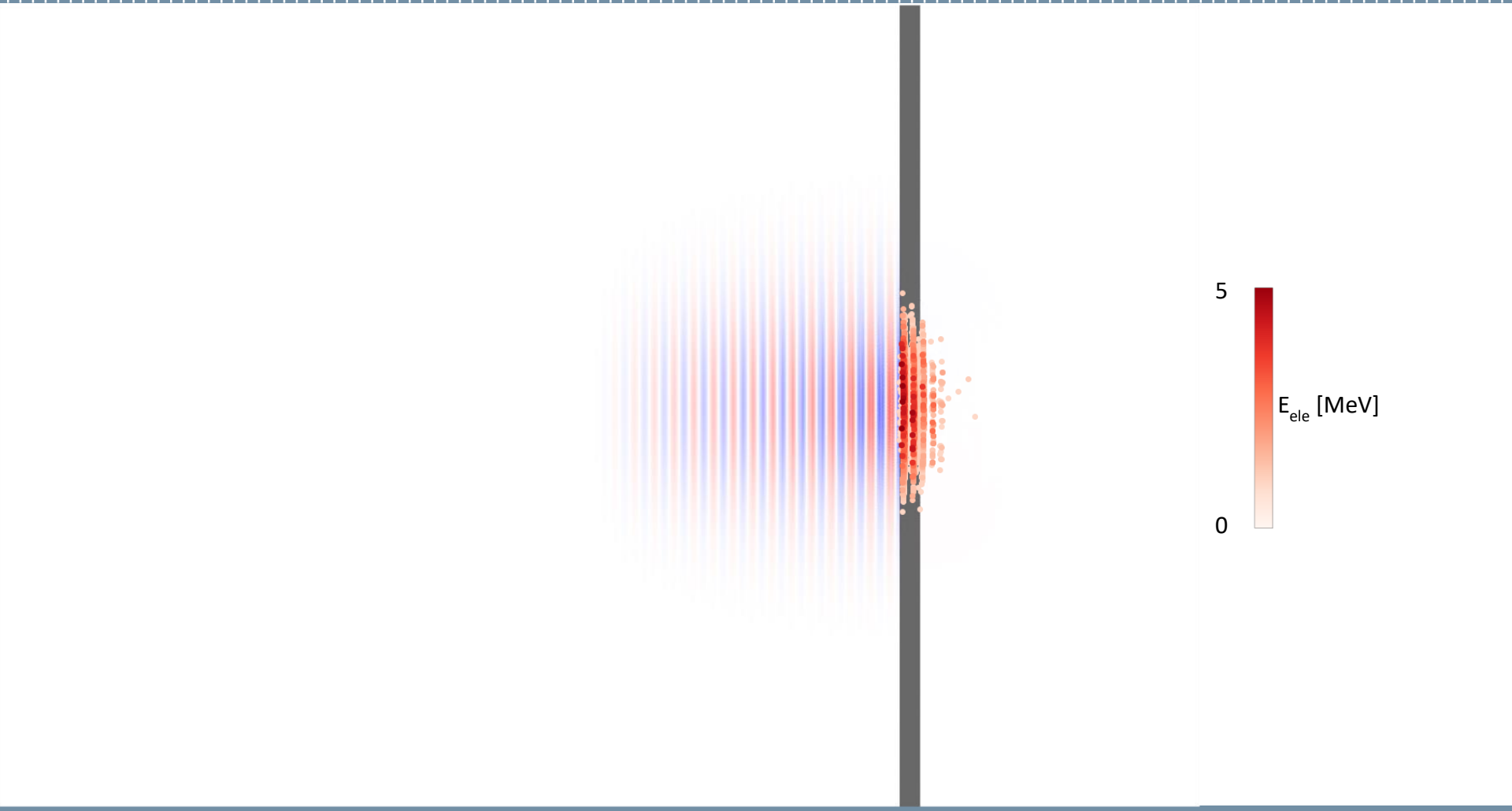
Ultra intense laser focused onto a **thin solid target** accelerates **energetic ions** (tens of MeV)



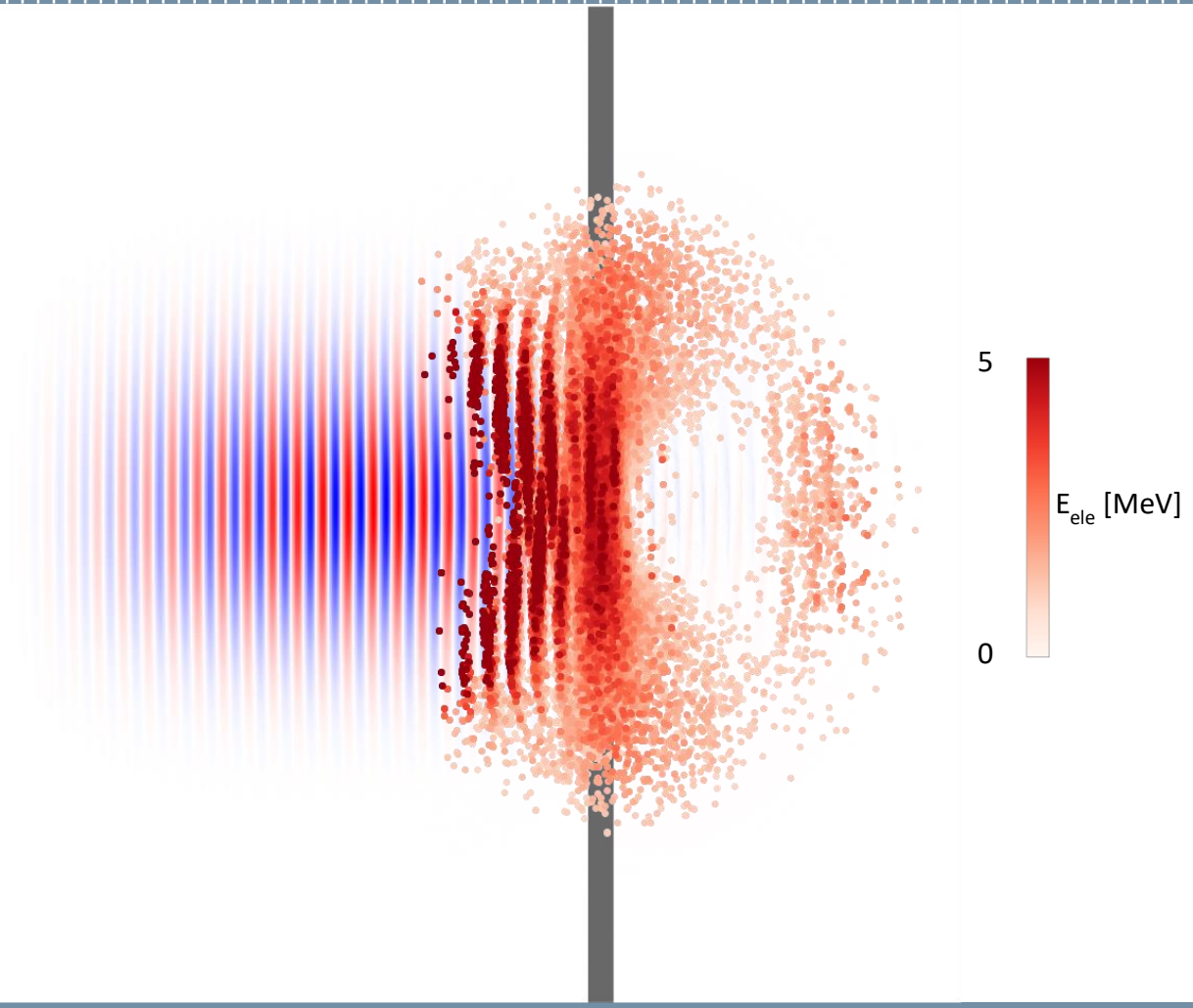
$I > 10^{19}$ W/cm^2
t ≈ μm



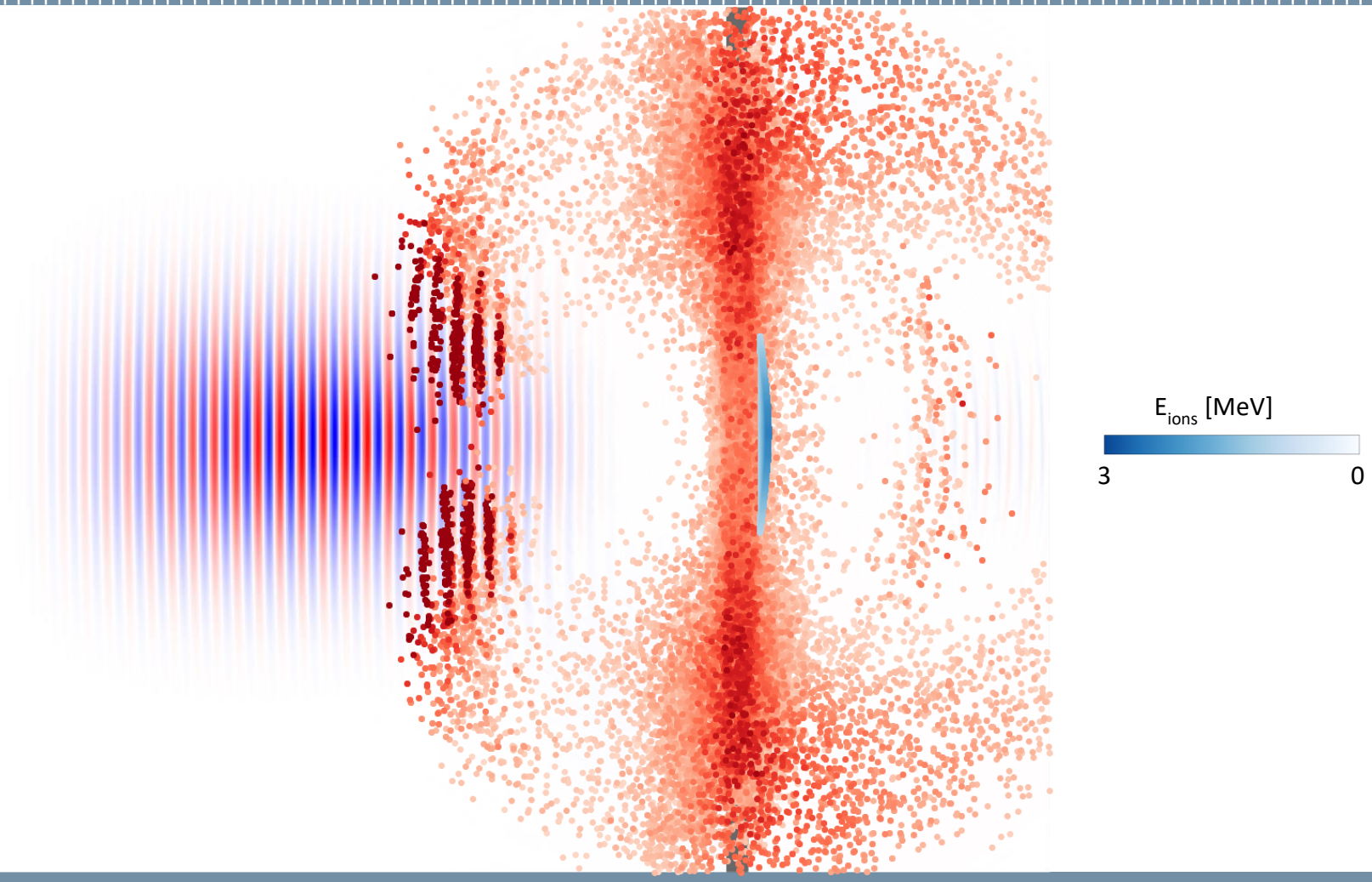
Hot electrons are generated at the surface



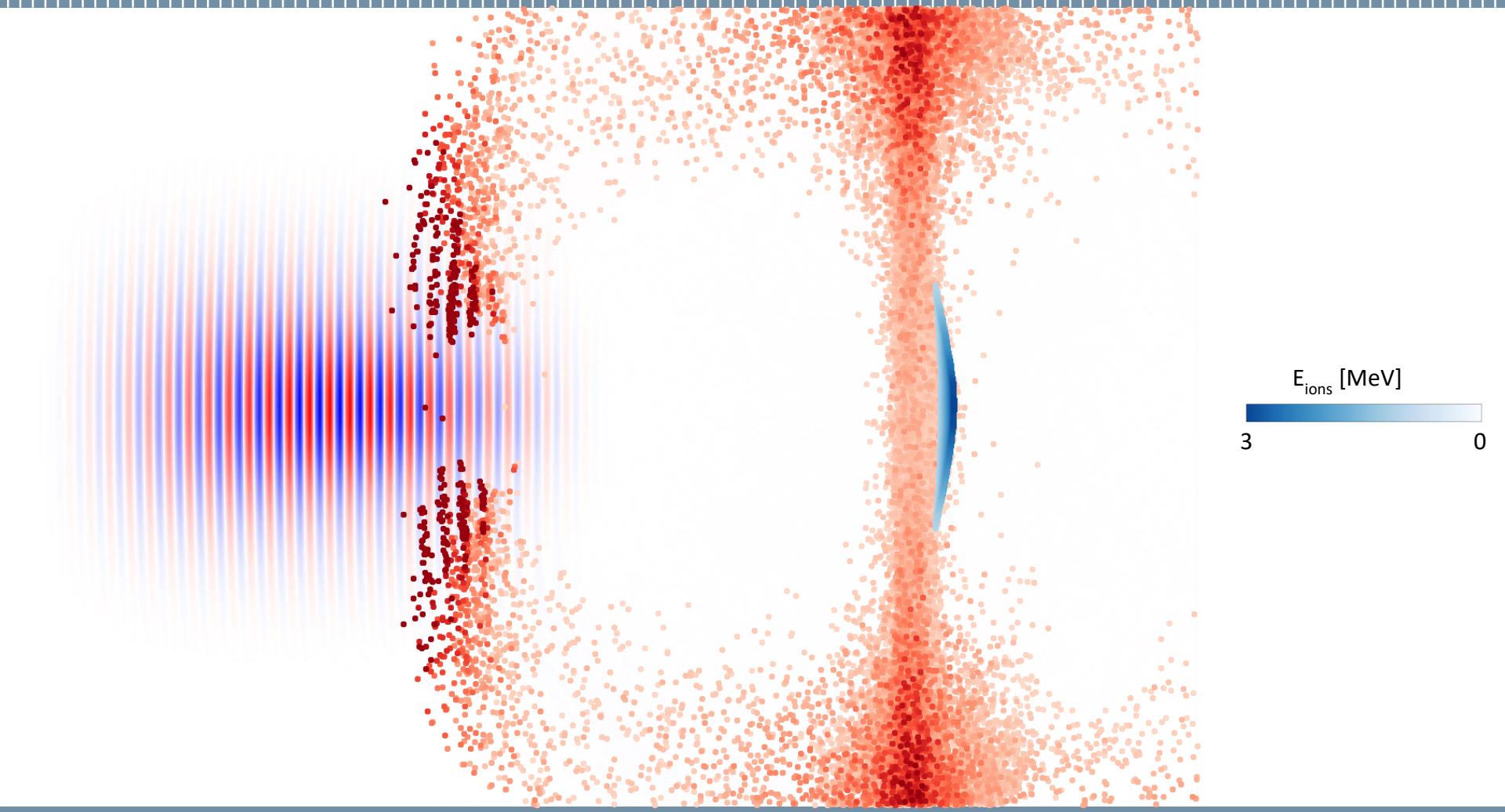
Hot electrons generate a sheath besides the target



Ions at the back are accelerated by the strong charge separation

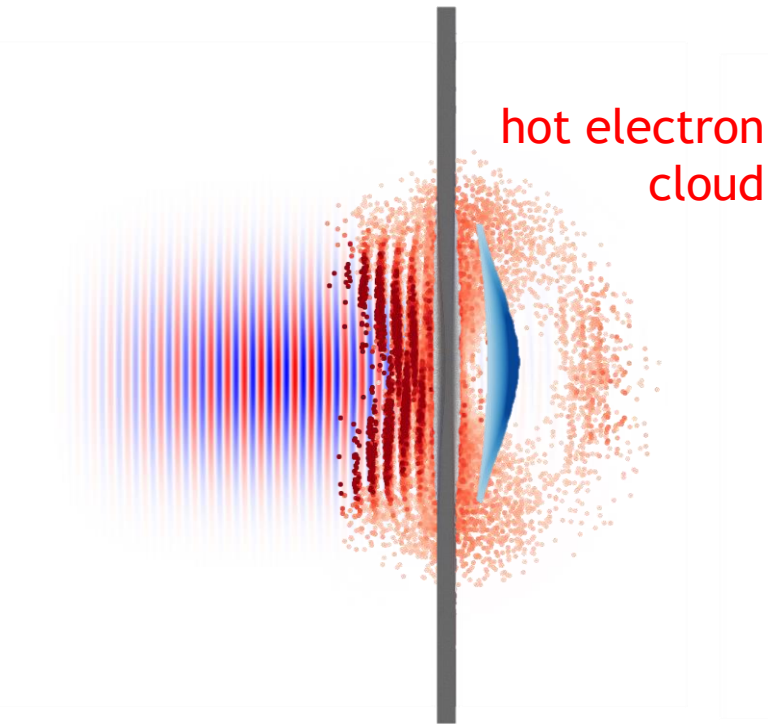


And most of the laser pulse is reflected → waste of energy

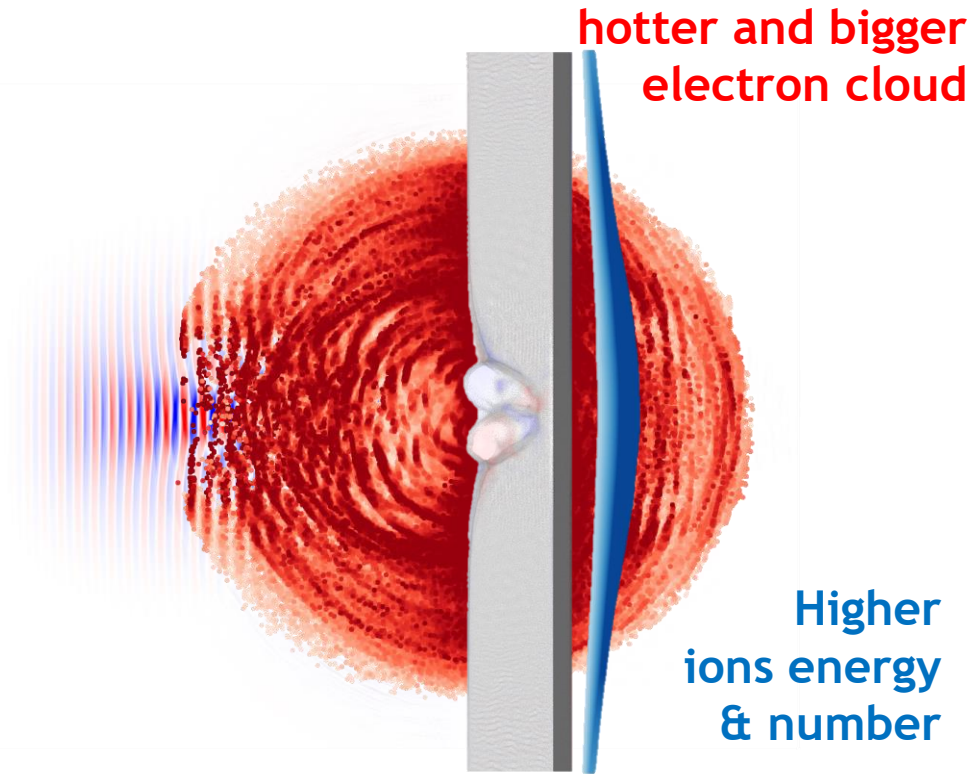


How can we increase laser plasma coupling?

Flat solid foil



Near critical density layer



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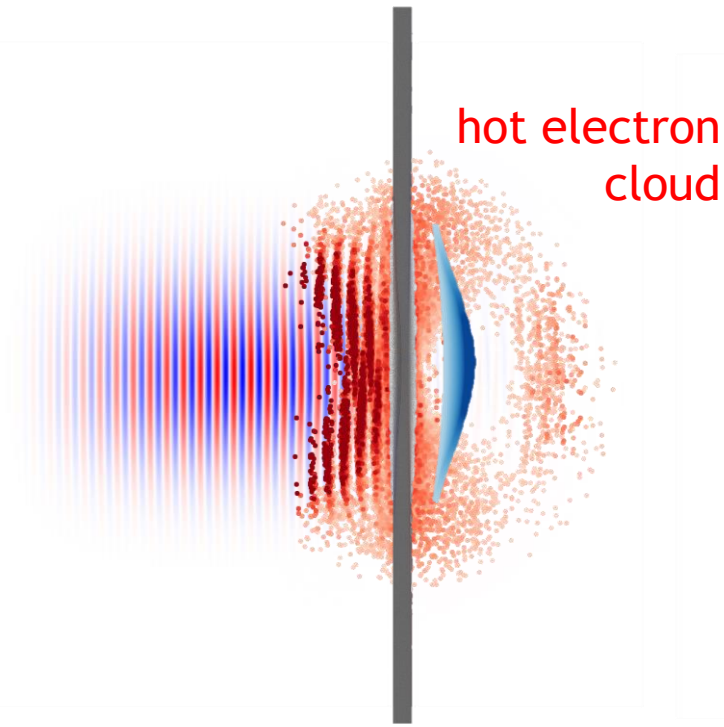

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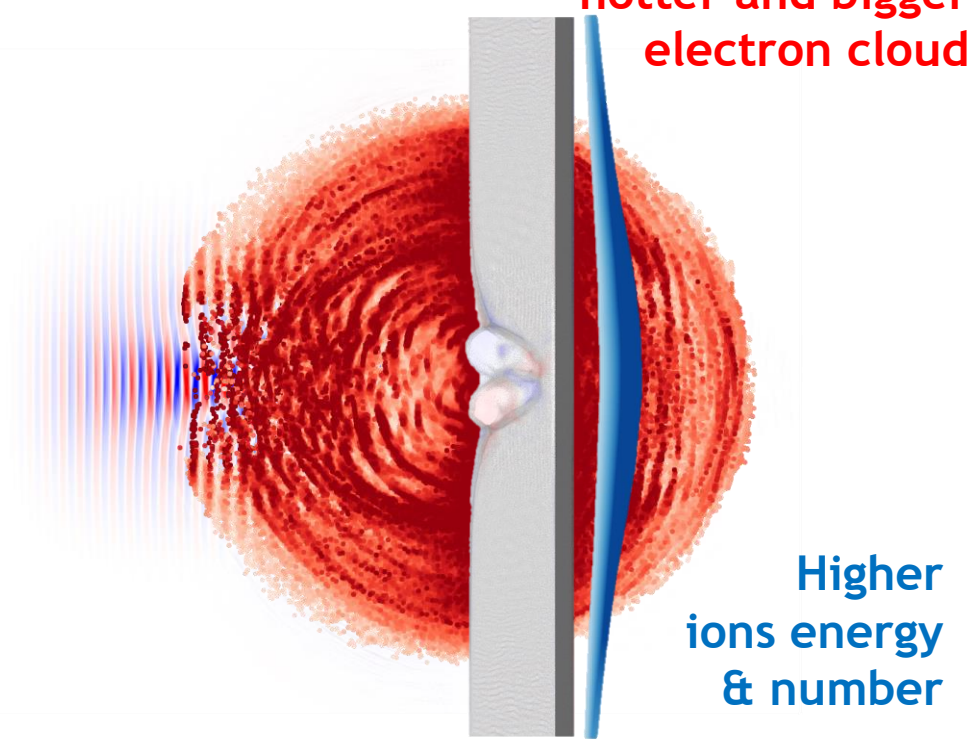
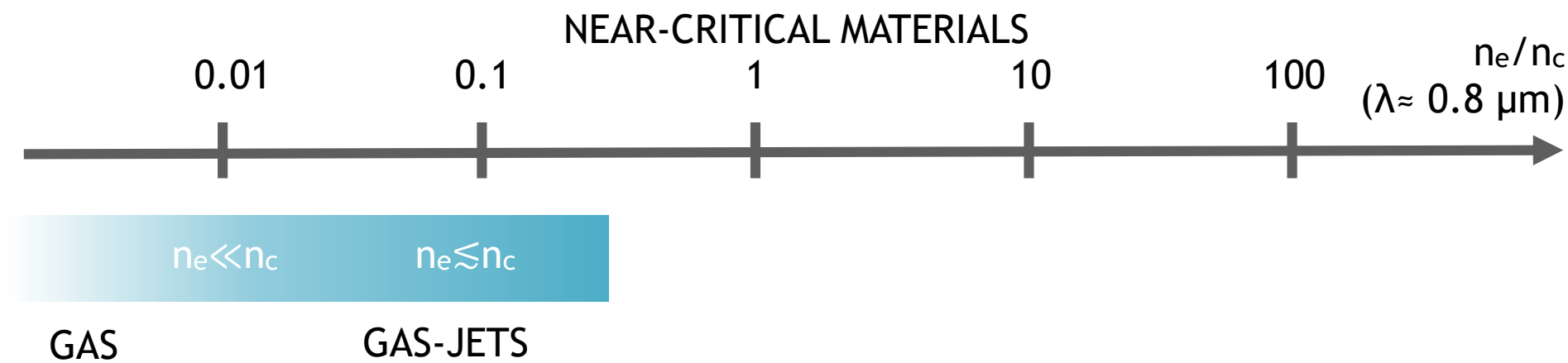


Target is the key!

What happens at the critical density?

underdense plasmas

- laser propagation
- low absorption



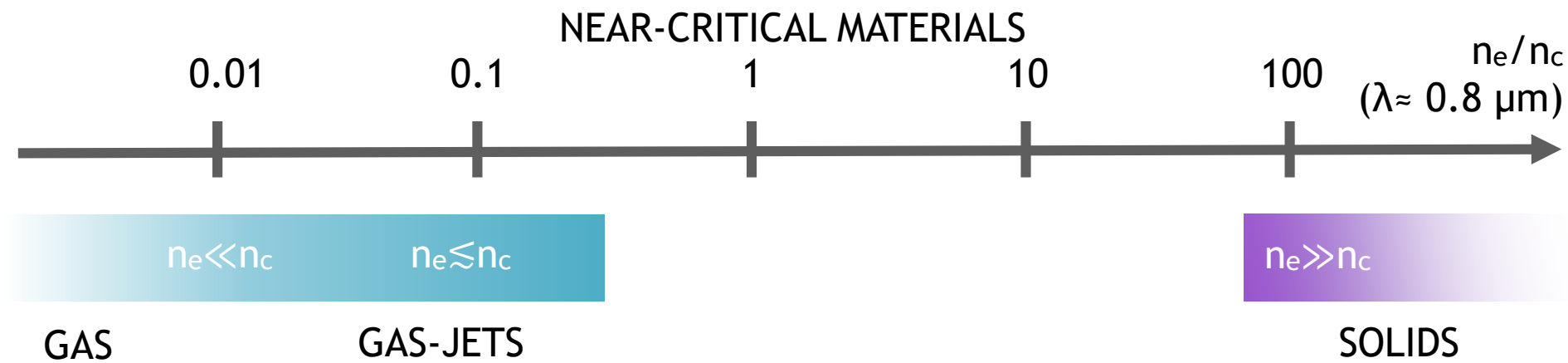
What happens at the critical density?

underdense plasmas

- laser propagation
- low absorption

overdense plasmas

- laser reflection
- surface interaction



What happens at the critical density?

underdense plasmas

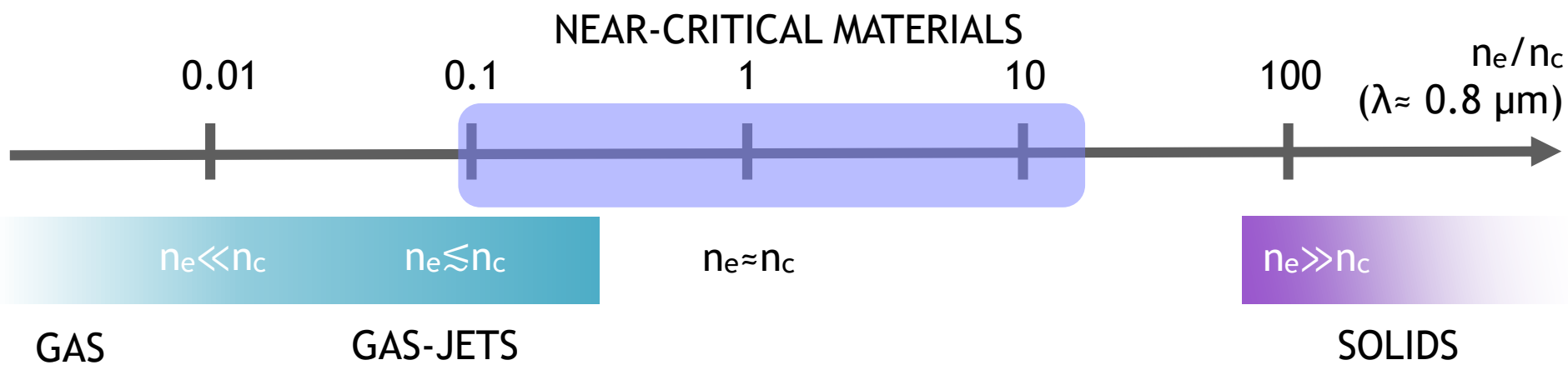
- laser propagation
- low absorption

near-critical plasmas

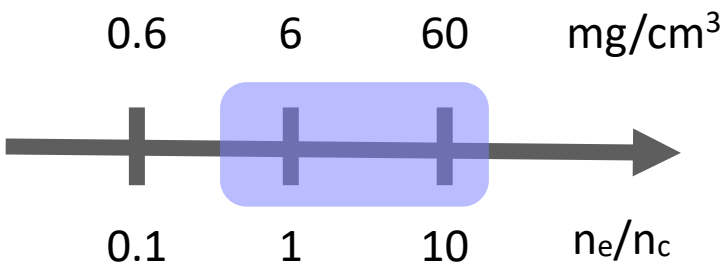
- **strong interaction**
- **complex regime**

overdense plasmas

- laser reflection
- surface interaction



Producing near critical materials is challenging



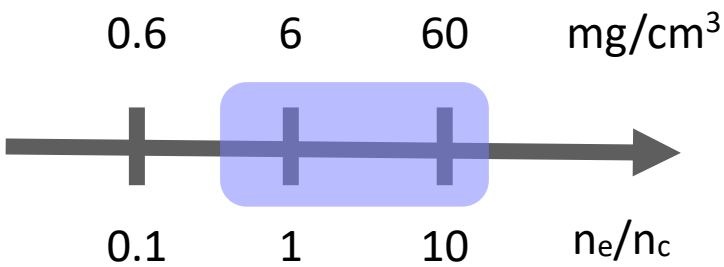
$\lambda \approx 0.8\ \mu m \rightarrow$ **$n_c \approx 6$ mg/cm^3 = 6 x density of air**

ultra-low density

Producing near critical materials is challenging

Bin, J. H., et al. *Physical review letters* 115.6 (2015): 064801.

Sylla, F., et al. *Review of Scientific Instruments* 83.3 (2012): 033507.



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<u>ultra-low density</u>

Some possibilities:

- Carbon nanotubes
- Very dense gas jets
- Foams

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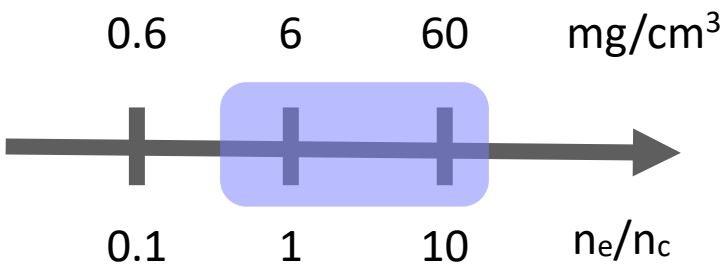

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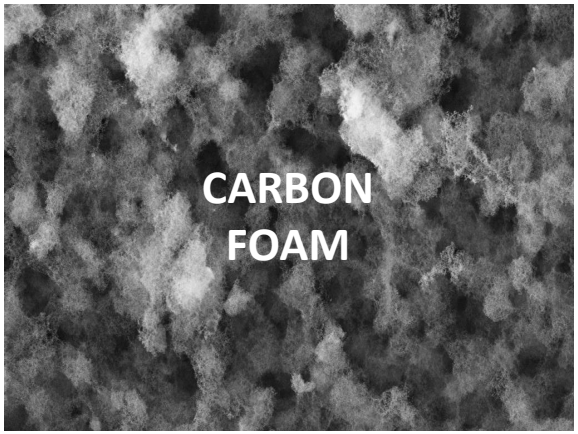

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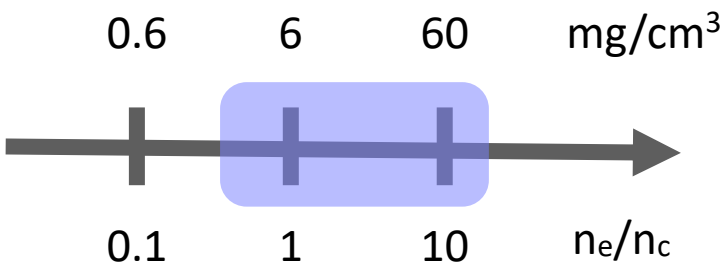

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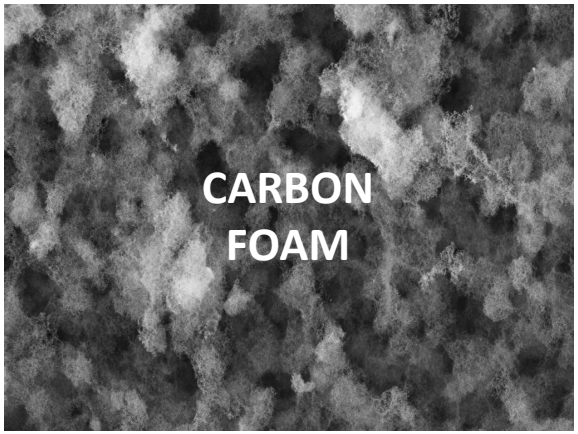

Some possibilities:

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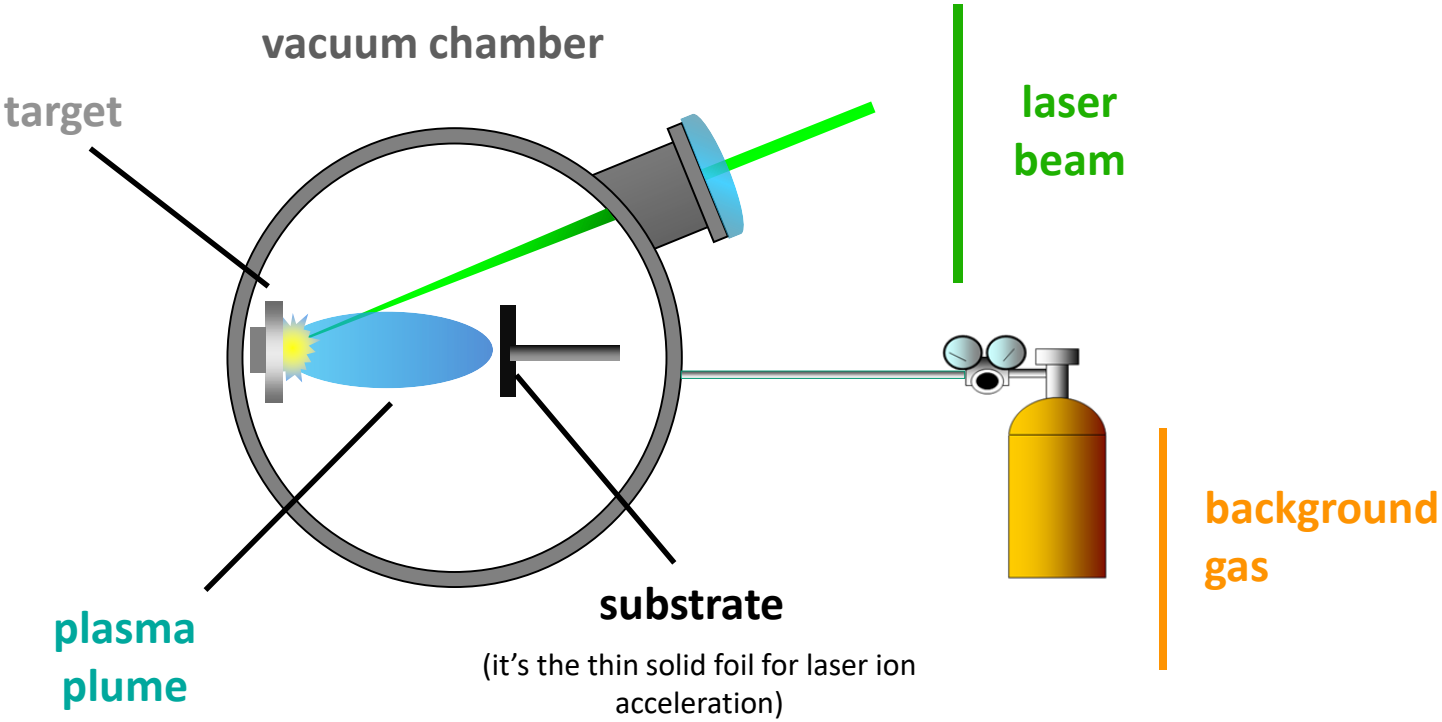
Additional challenges

- Density control and measurement
- Mechanical strength

Zani, Alessandro, et al. Ultra-low density carbon foams produced by pulsed laser deposition. *Carbon* 56 (2013): 358-365.

Carbon foams can be produced by Pulsed Laser Deposition (PLD)



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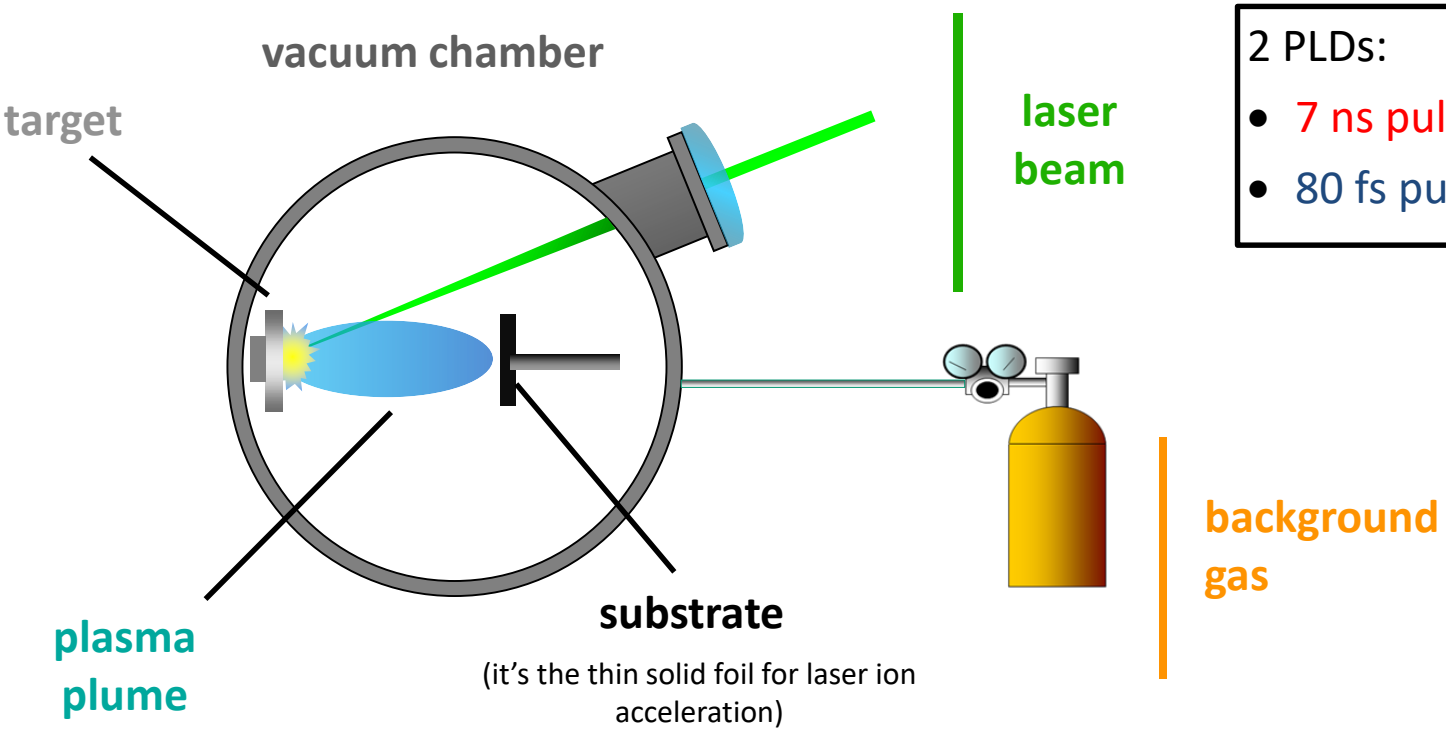
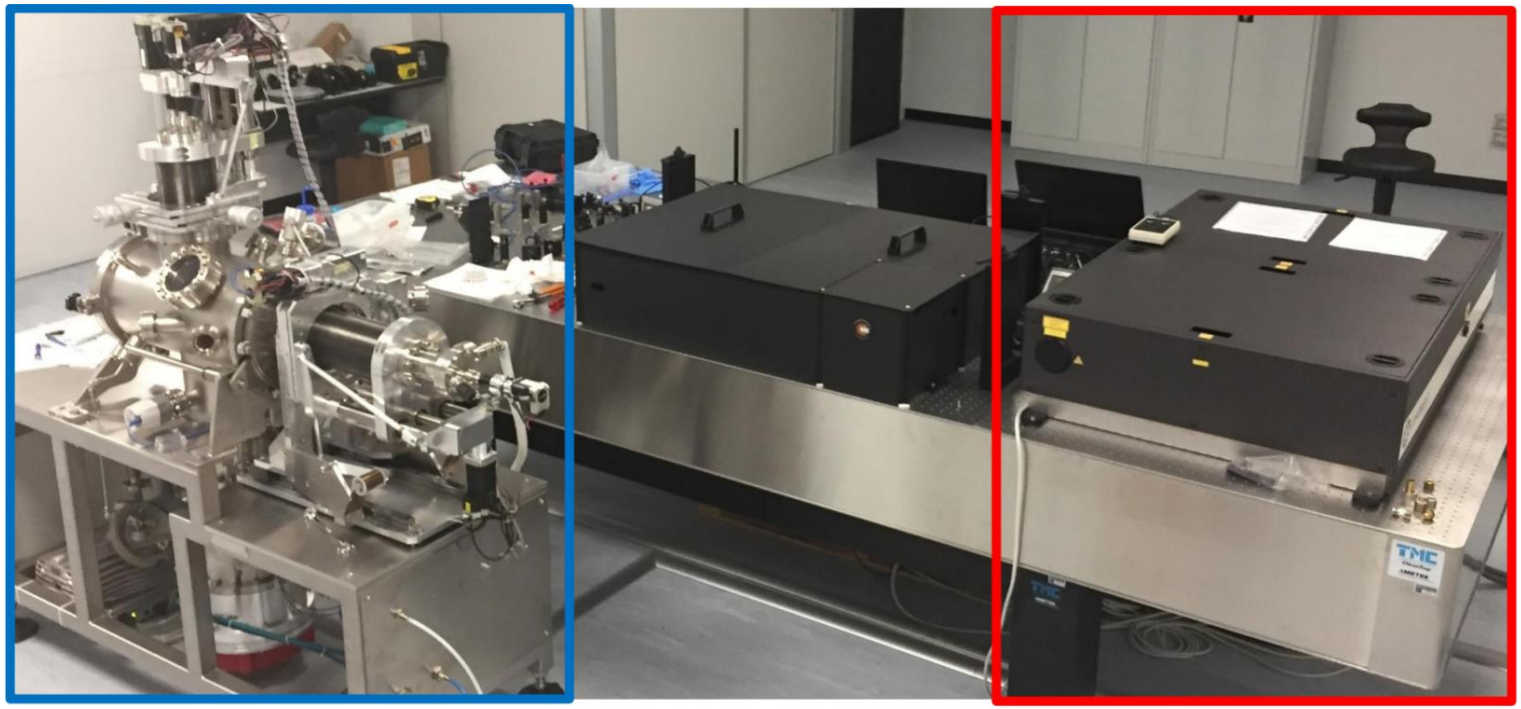


2 PLDs:

- 7 ns pulses, 10 Hz rep rate
- 80 fs pulses, 1 kHz rep rate

fs-PLD



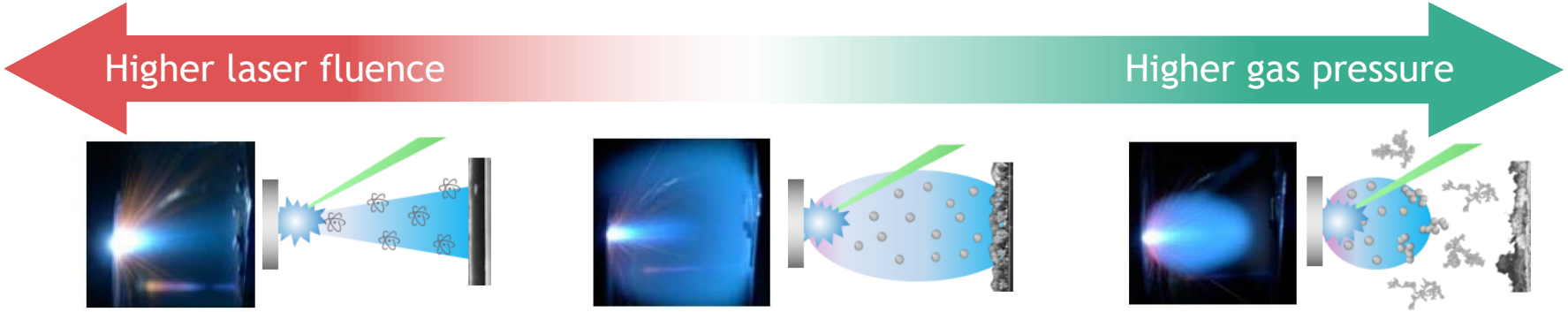
fs-PLD interaction chamber:

- PLD mode + laser processing
- Up to 4 targets
- Upstream/downstream pressure control
- Fast substrate heater

Coherent Astrella ™:

- Ti:Sapphire, λ=800 nm
- Max E_p = 5 mJ
- Pulse duration < 100 fs
- Rep rate = 1 kHz

Towards ultra-low density



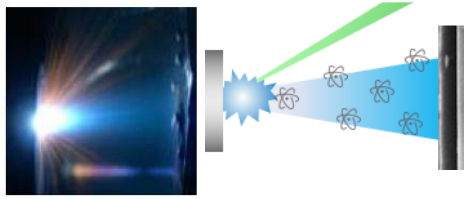
«atom by atom» deposition

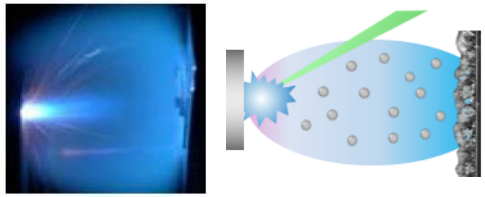
nanoparticles aggregates deposition

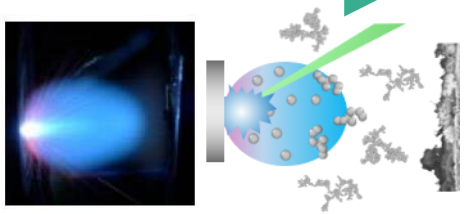
Towards ultra-low density

Higher laser fluence

Higher gas pressure







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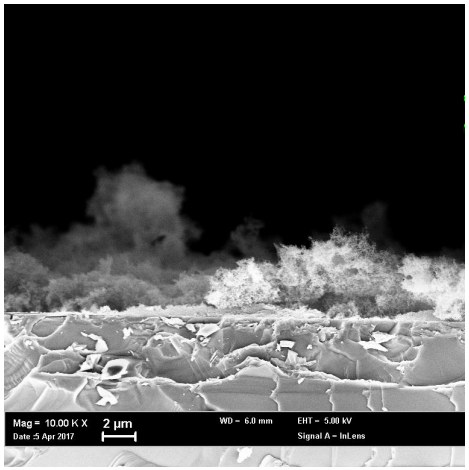
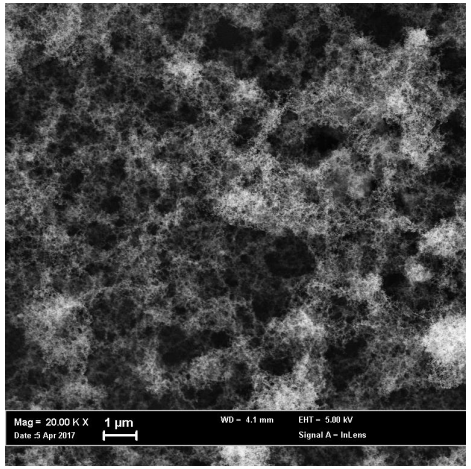
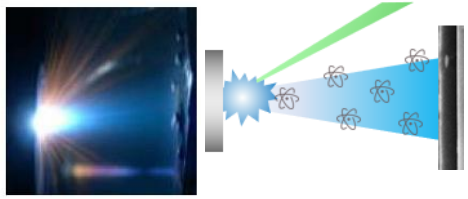


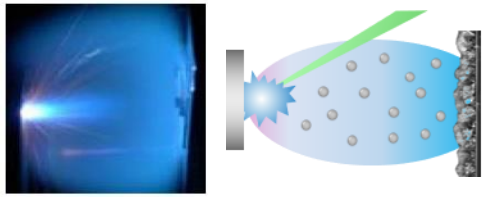


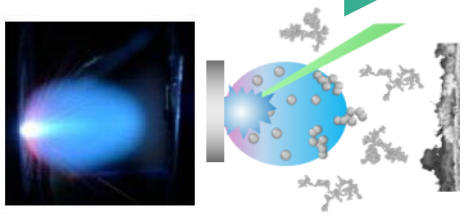
Towards ultra-low density

Higher laser fluence

Higher gas pressure







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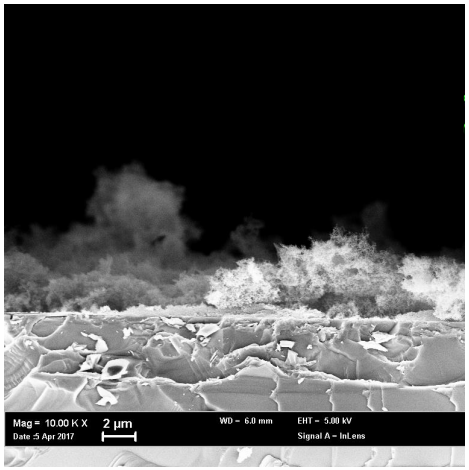
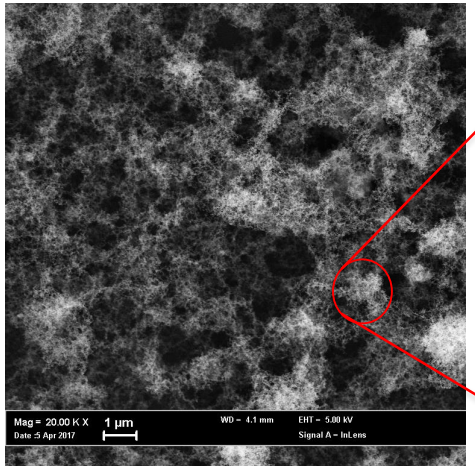
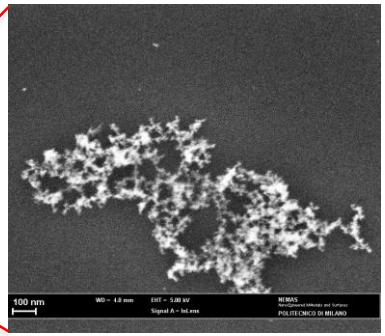
ultra-low density

foam «building blocks»



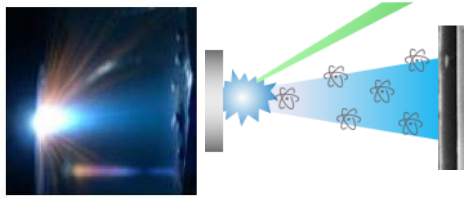


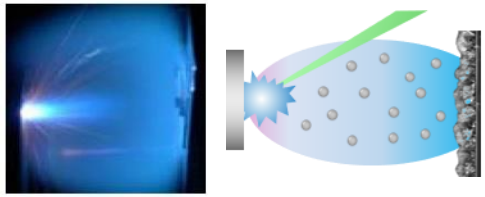


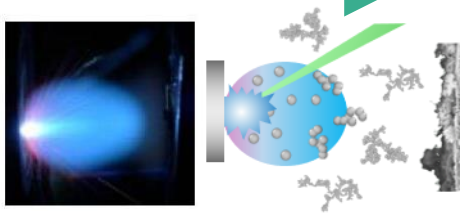
Towards ultra-low density

Higher laser fluence

Higher gas pressure







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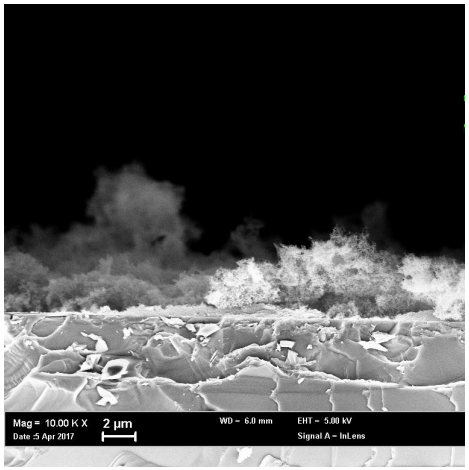
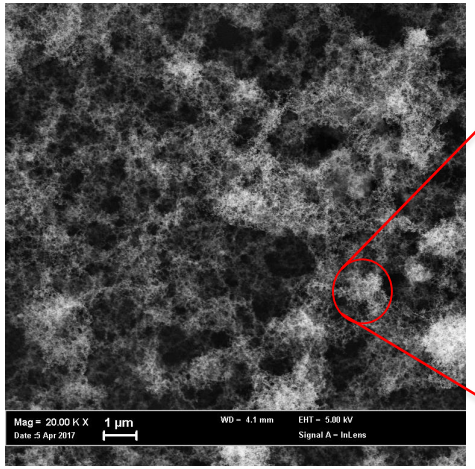
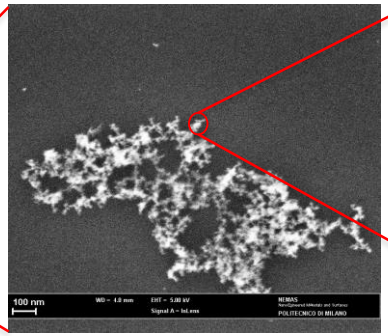
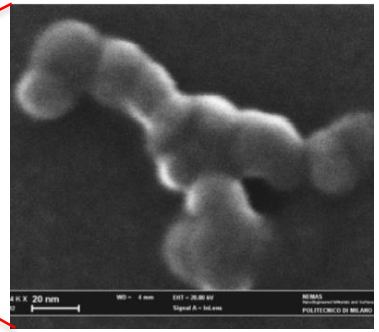
ultra-low density

foam «building blocks»



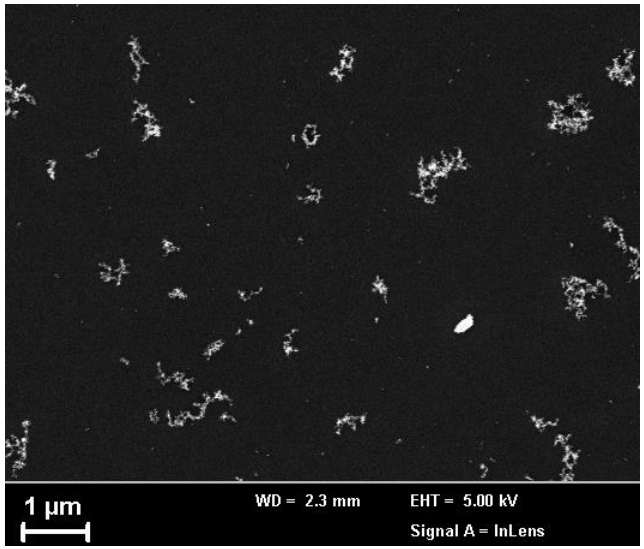






Tuning the foam density

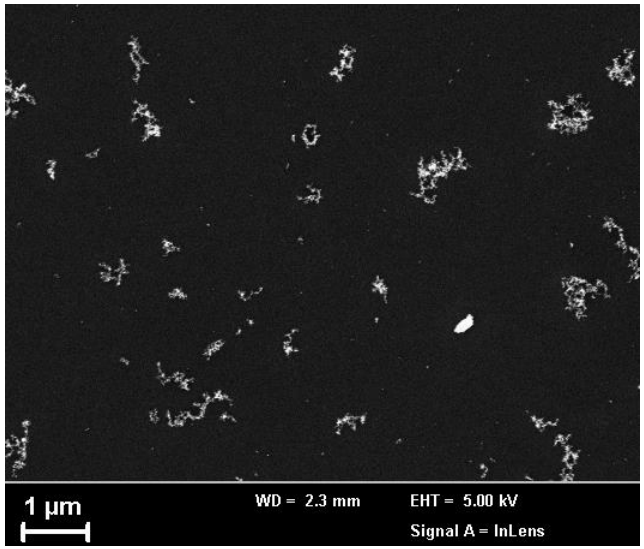
Foam «building blocks» dimension
determine foam density & homogeneity

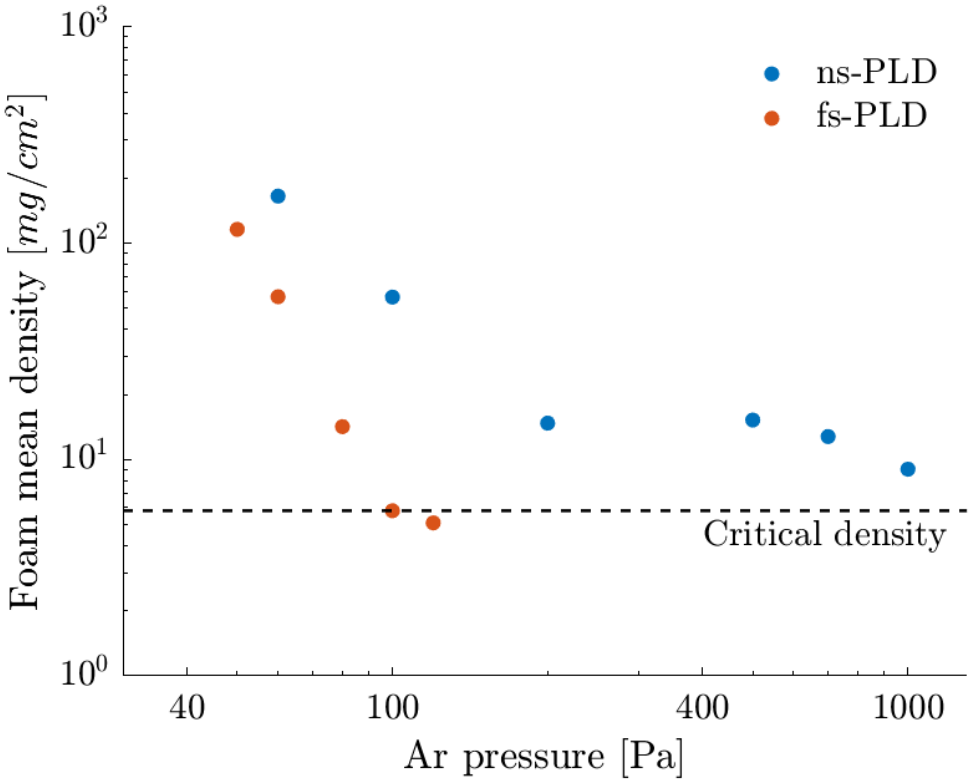


Tuning the foam density

Foam «building blocks» dimension
determine foam density & homogeneity

Controlled by the
chamber pressure





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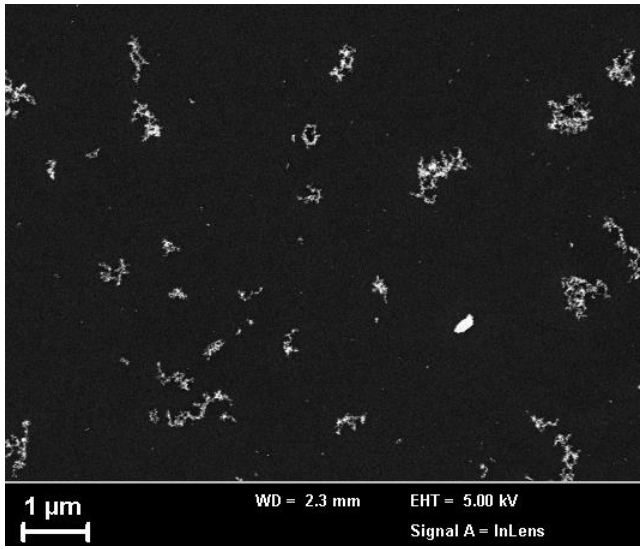

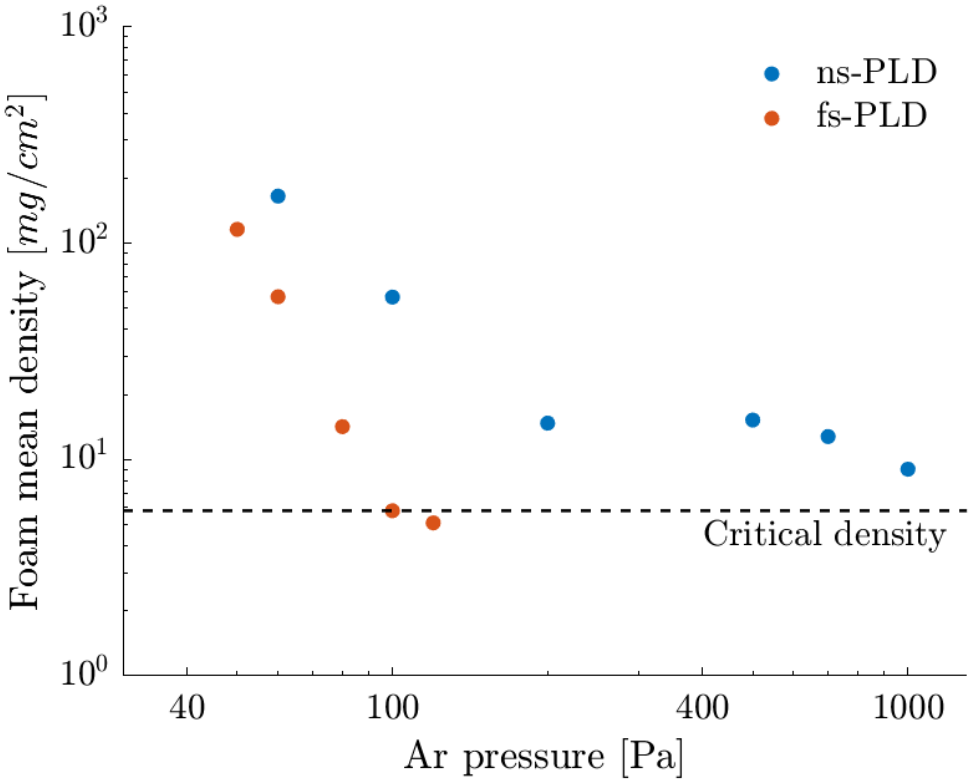

Near-critical densities can be achieved!

Impossible to retrieve foam density with standard methods!

New technique for **film areal density measurement** based on Energy Dispersive X-ray Spectroscopy (EDS)

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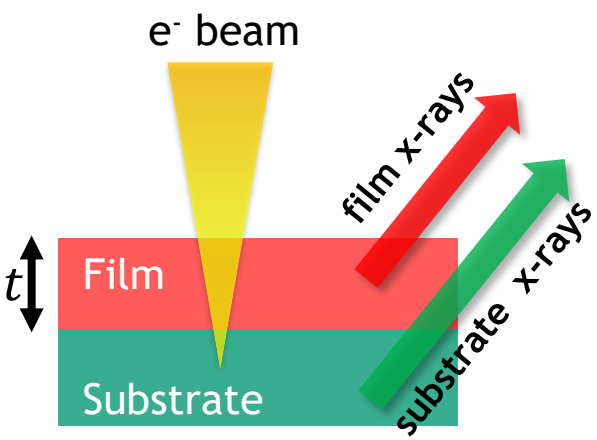

$$\frac{I_{film}}{I_{sub}} = f(t)$$

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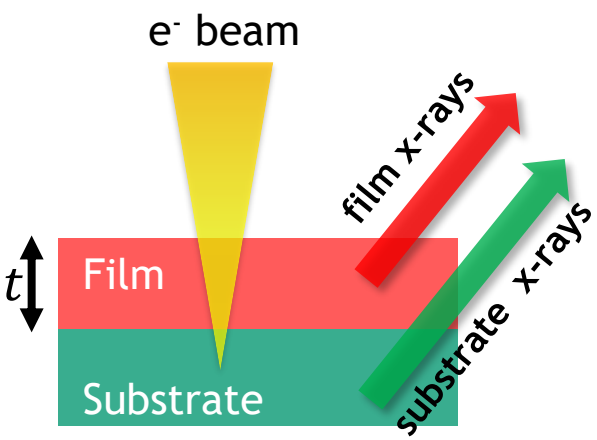

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theoretical model:

Solution of transport equation for electrons

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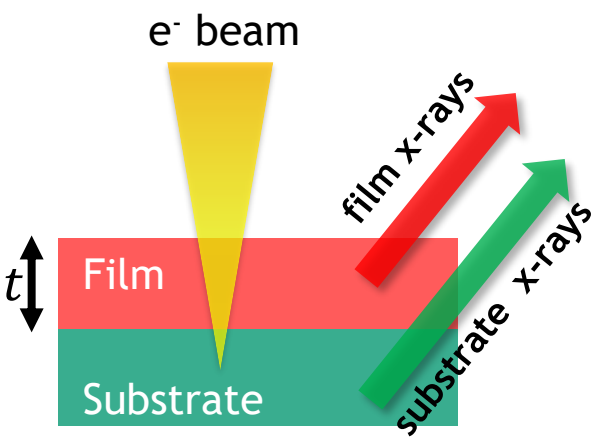

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theoretical model:

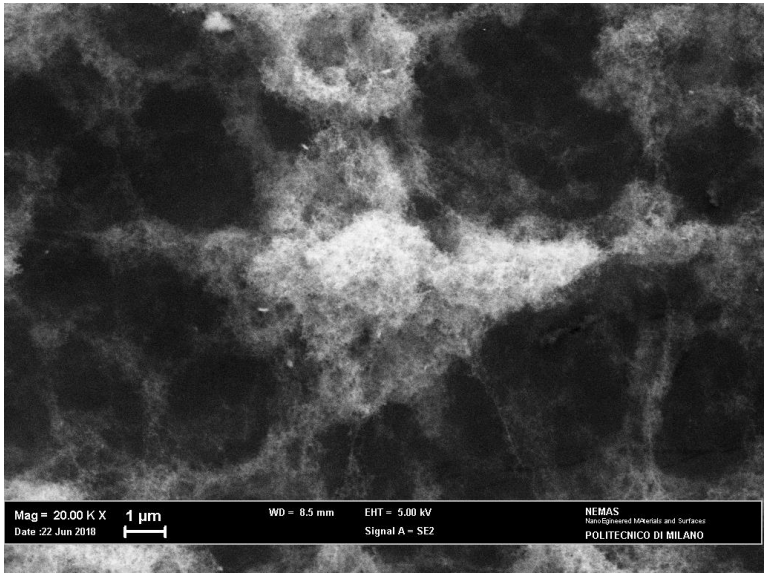
Solution of transport equation for electrons

Validated with benchmarks from **X-Ray Reflection (XRR)**

Pazzaglia A., et al., *Materials Characterization* (2019), in press

New characterization capabilities

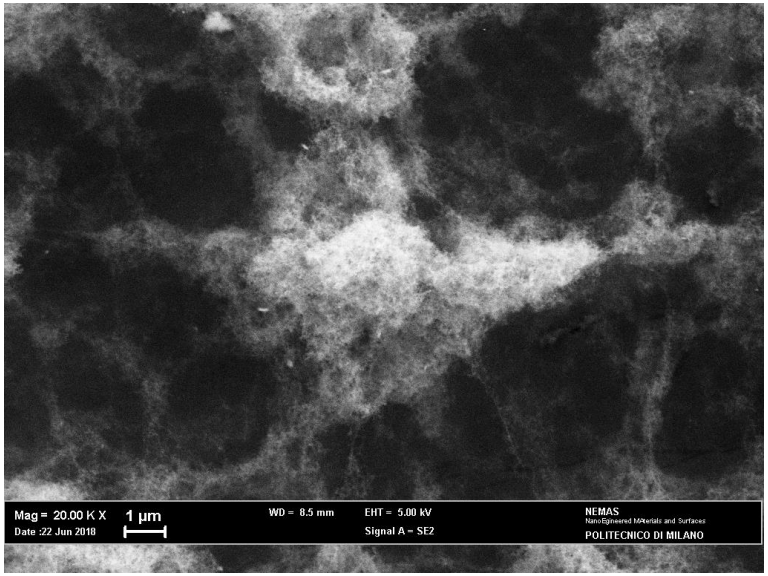
SEM image



From EDS map

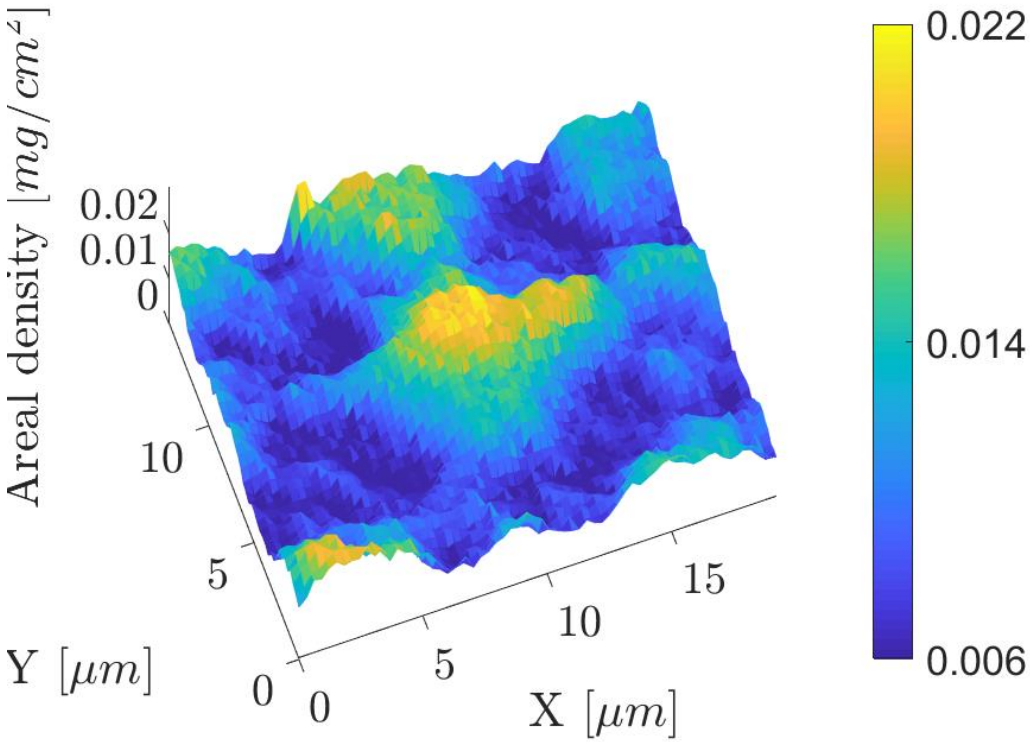
New characterization capabilities

SEM image



From EDS map

Retrieval of **areal density** 2D profile



Modeling the foam structure

Diffusion Limited Cluster-Cluster Aggregation (DLCA) Meakin, Paul *Physical Review Letters* 51.13 (1983)

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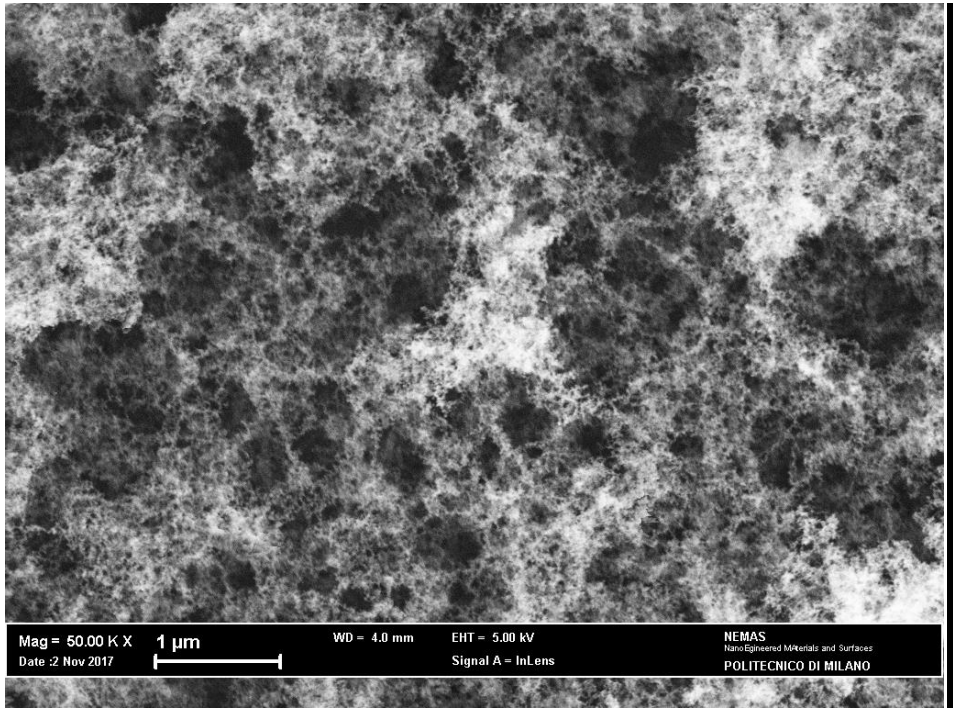
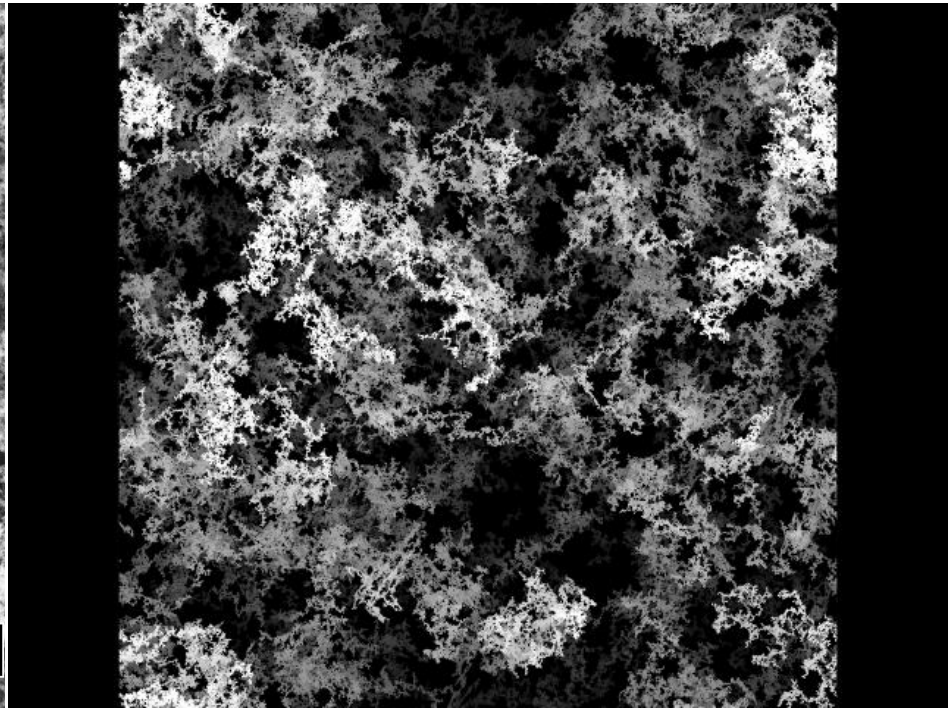


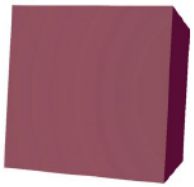
DLCA simulation



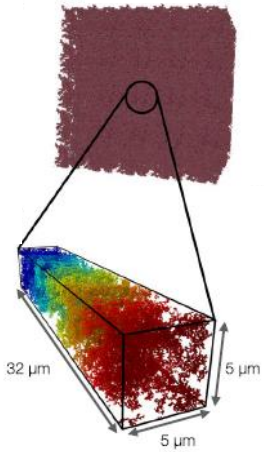
Maffini A. Pazzaglia A., et al. , submitted

Towards more realistic 3D PIC simulations

Homogeneus Foam



Nanostructured Foam



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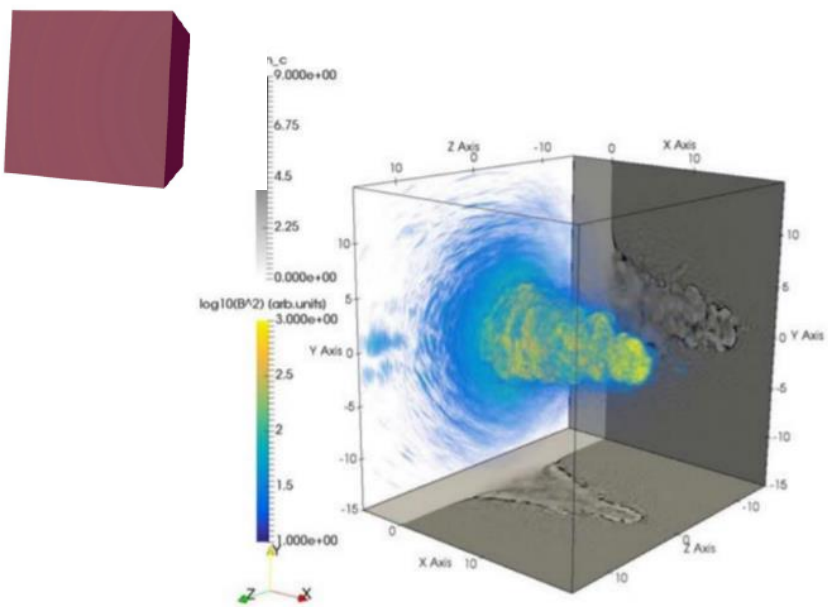

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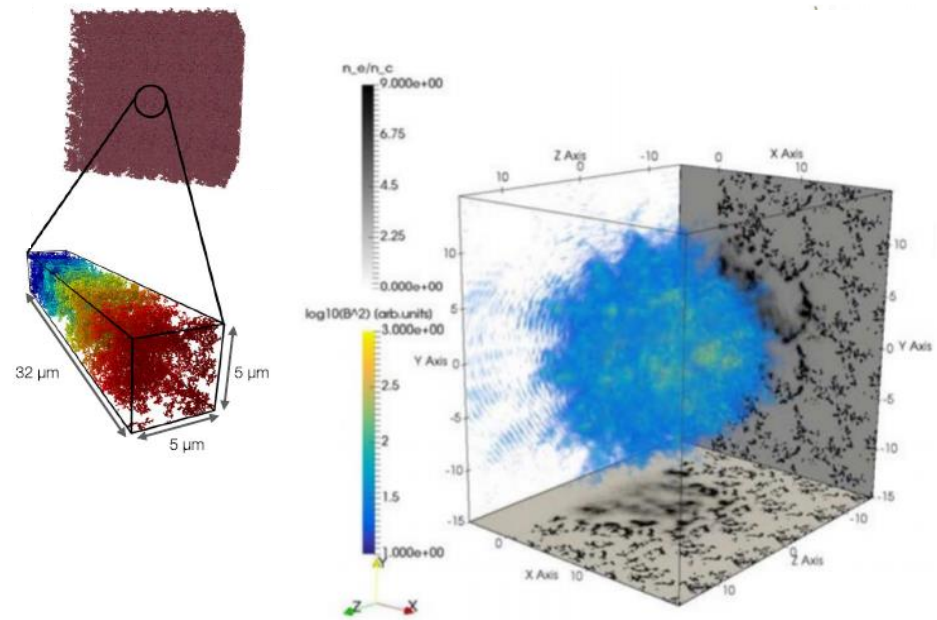

Fedeli, L., Formenti, A., Cialfi, L., Pazzaglia, A., & Passoni, M. (2018). Ultra-intense laser interaction with nanostructured near-critical plasmas. *Scientific reports*, *8*(1), 3834.

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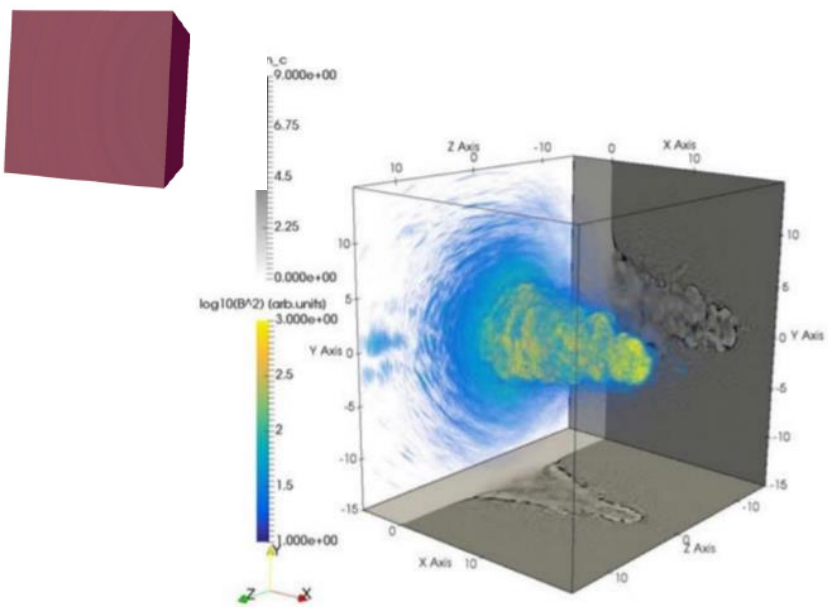

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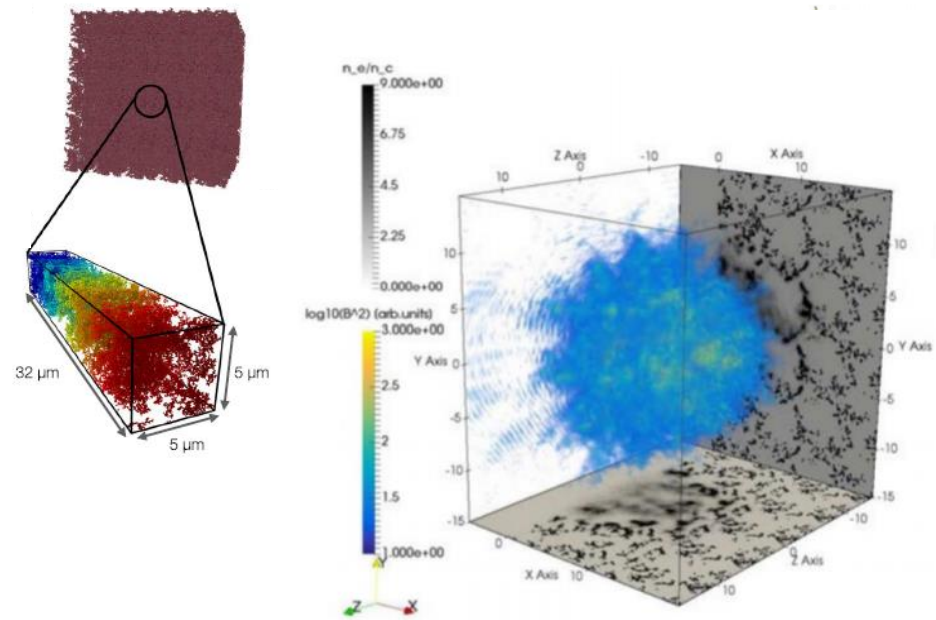

Simulations shed a light on the differences between **idealized foam vs realistic foam**

Fedeli, L., Formenti, A., Cialfi, L., Pazzaglia, A., & Passoni, M. (2018). Ultra-intense laser interaction with nanostructured near-critical plasmas. *Scientific reports*, *8*(1), 3834.

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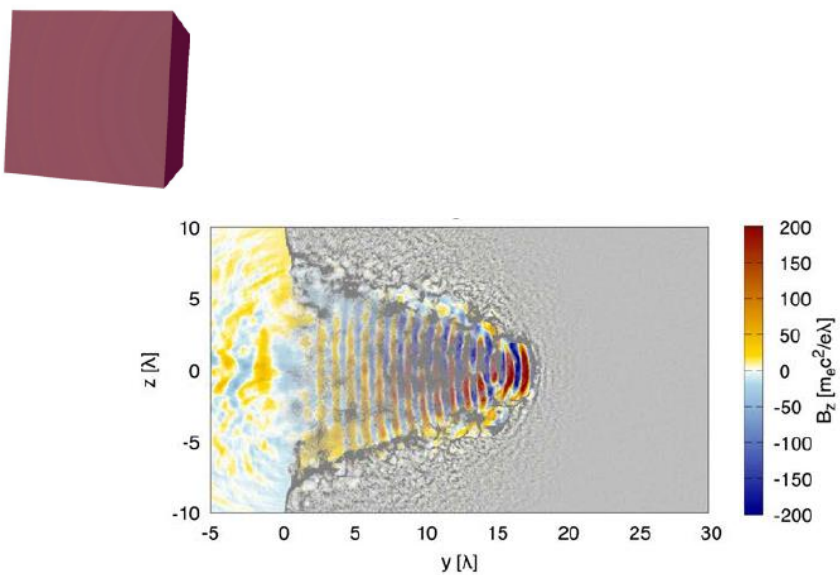

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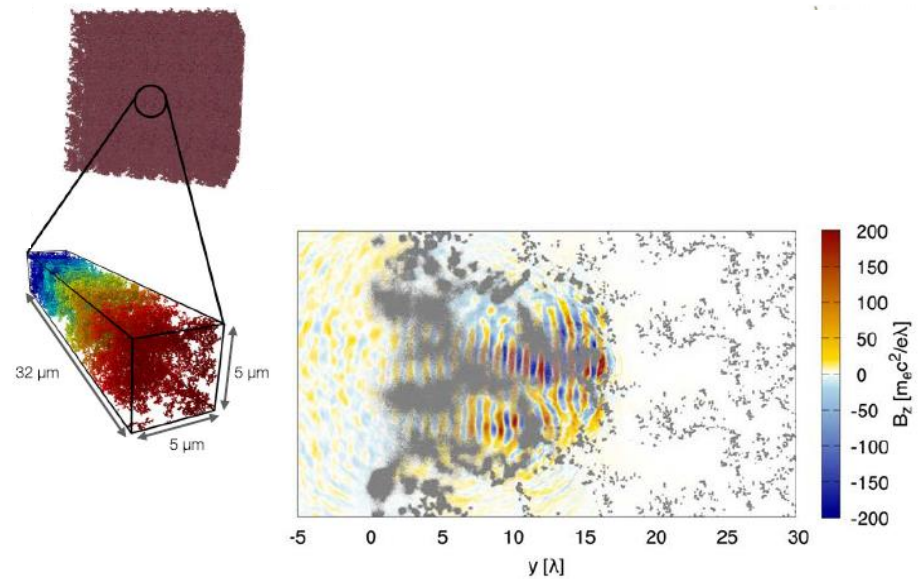
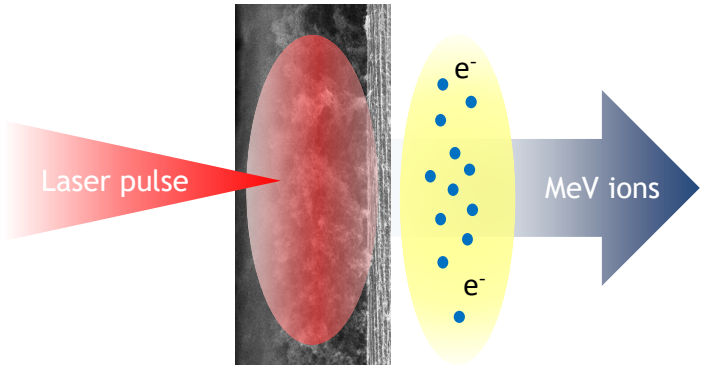


- Laser pulse is more scattered
- Laser reflection is reduced
- Part of energy lost in Coulomb Explosion

Fedeli, L., Formenti, A., Cialfi, L., Pazzaglia, A., & Passoni, M. (2018). Ultra-intense laser interaction with nanostructured near-critical plasmas. *Scientific reports*, *8*(1), 3834.

The foam based target does work!



Passoni, Matteo, et al. *Plasma Physics and Controlled Fusion* 56.4 (2014): 045001.
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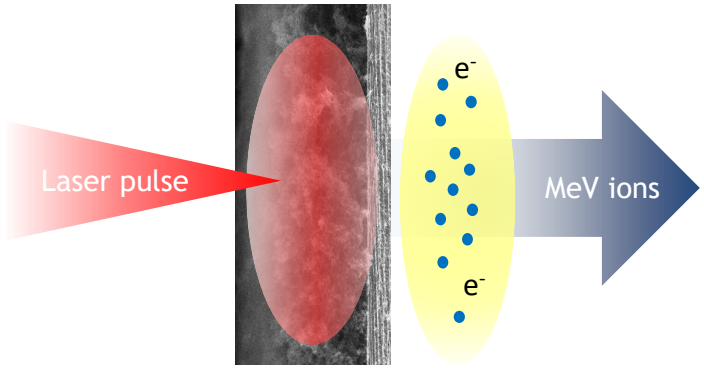

DRACO laser
1J, 30 fs, ≈**10^{20} W/cm^2**

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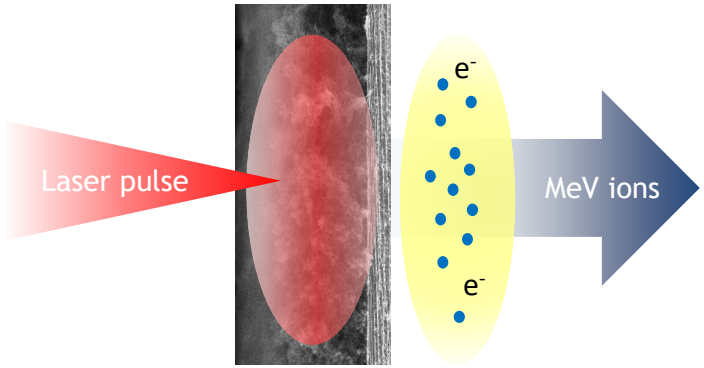

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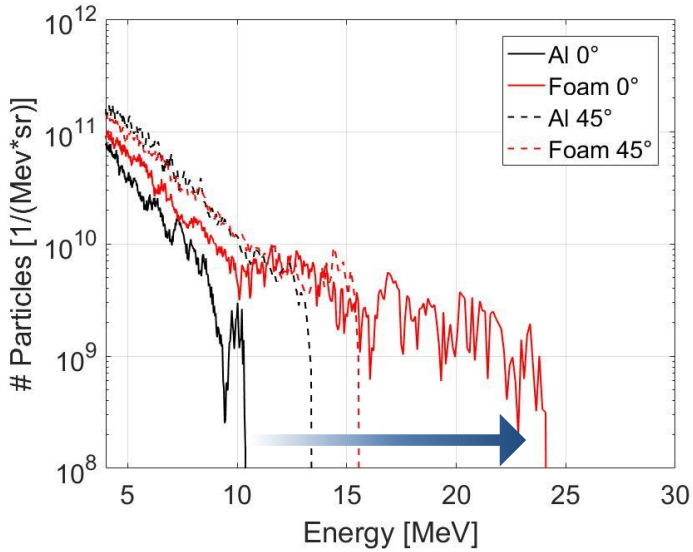
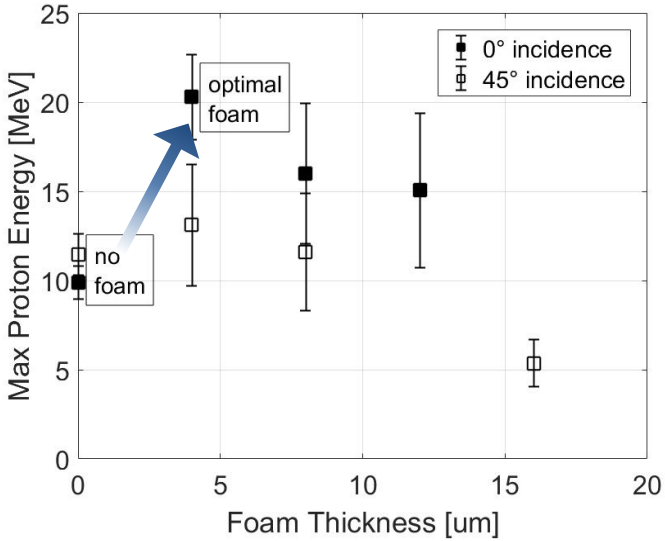
SEE FLORIAN KROLL POSTER





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Conclusions

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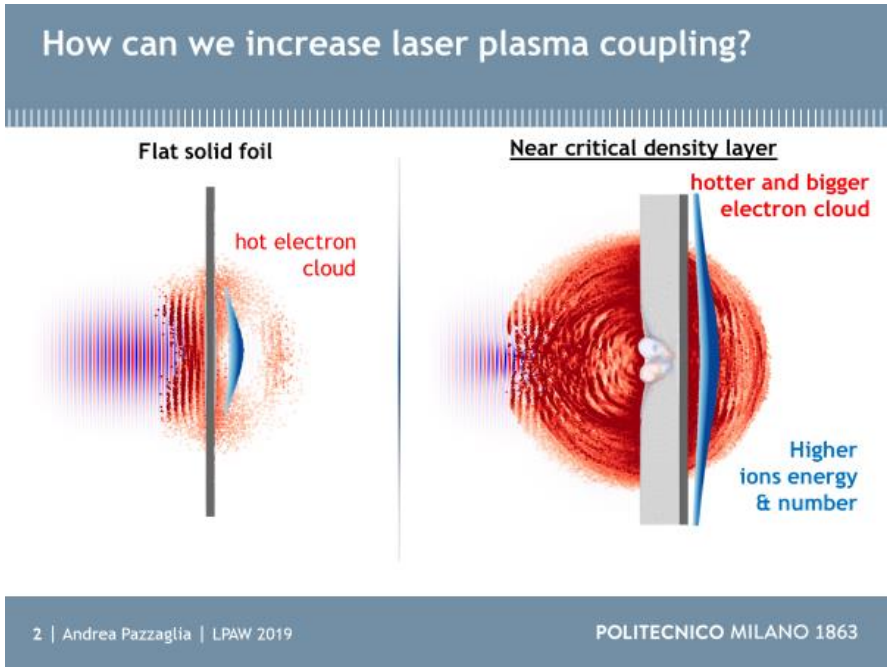

Conclusions

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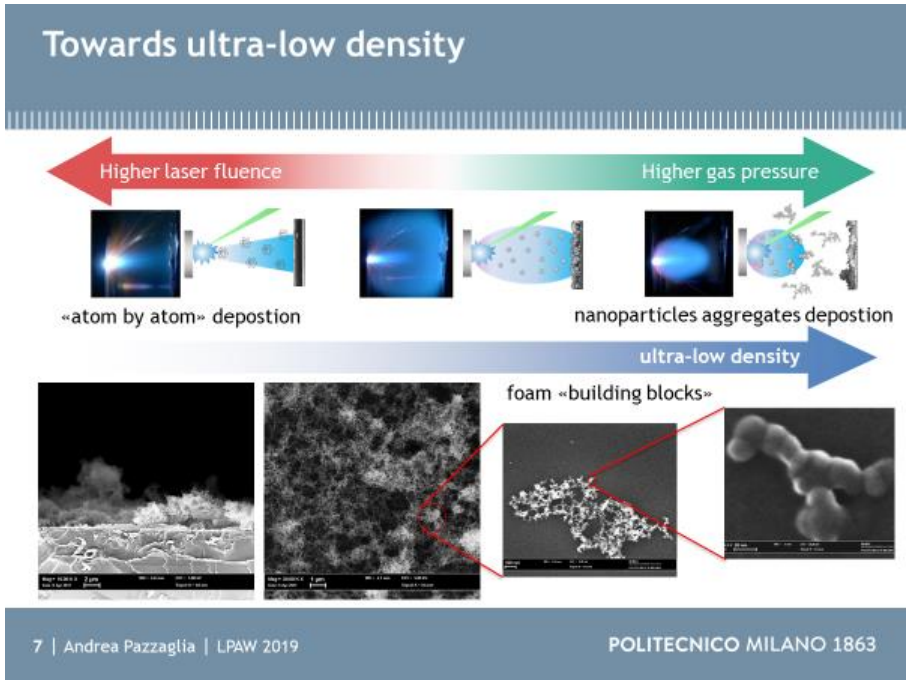
  - ❖ Foam deposition, characterization and modeling



Conclusions

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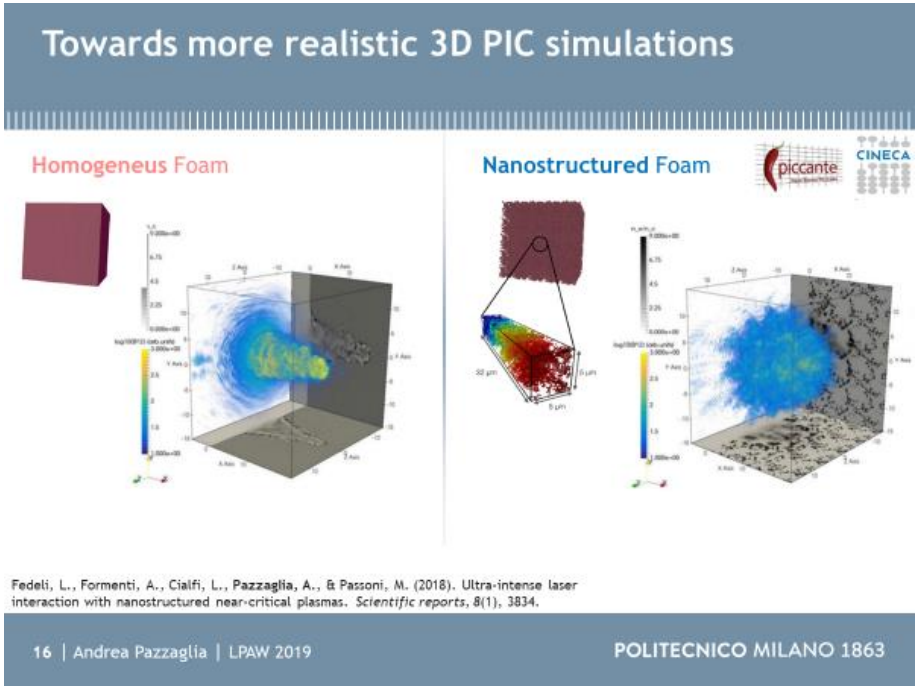
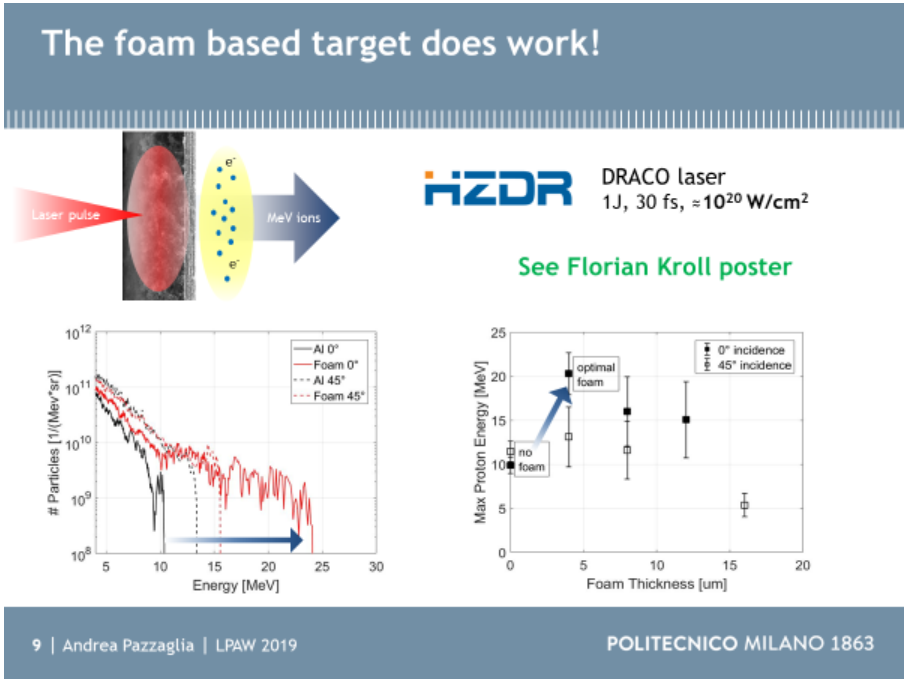


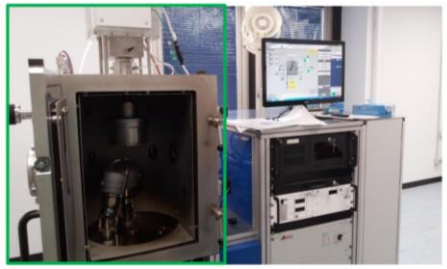
Conclusions

- Target is the key
- Advancements in double layer foam based targets
  - ❖ Foam deposition, characterization and modeling
  - ❖ Realistic 3D simulations
- Ion acceleration experiments

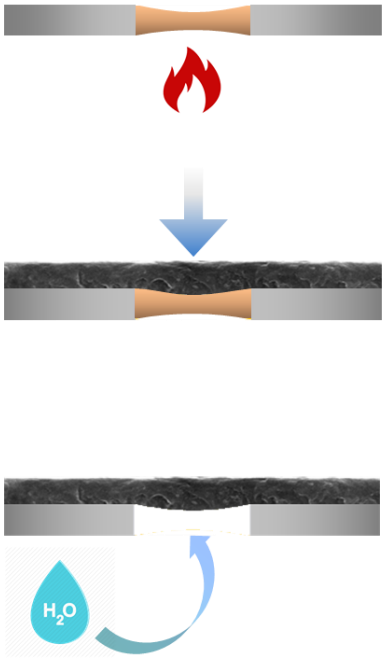


Future perspectives

High Power Impulse Magnetron Sputtering (HiPIMS)



- Integrated target
  - ❖ Substrate production



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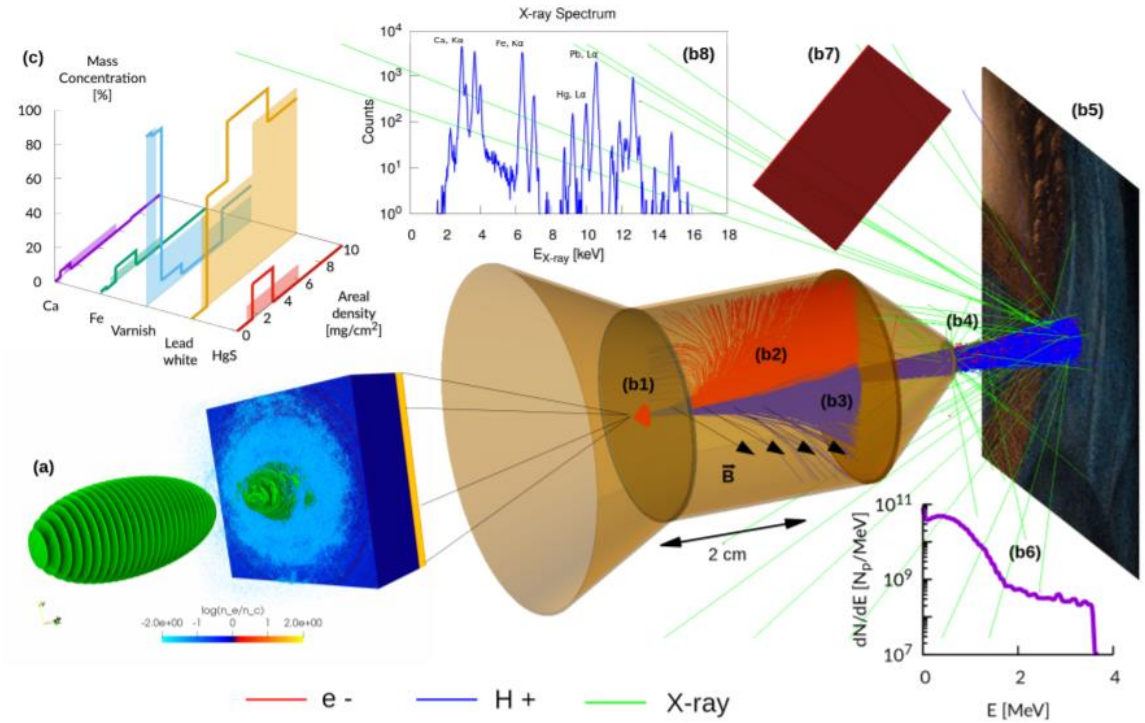
Passoni M., Fedeli L and Mirani F. Superintense Laser-driven Ion Beam Analysis (2019). *Scientific Reports*

- Applications
  - ❖ Ion Beam Analysis



Future perspectives

- Integrated target
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- Applications
  - ❖ Ion Beam Analysis
  - ❖ Neutron & Radioisotopes production

A. Tentori Master's thesis, Politecnico di Milano, Italy (2018)
F. Arioli Master's thesis, Politecnico di Milano, Italy (2019)
A. Giovannelli Master's thesis, Politecnico di Milano, Italy (2019)

Future perspectives

- Integrated target
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  - ❖ Ion Beam Analysis
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  - ❖ Dedicated experiments

Acknowledgments

ERC-2014-CoG No. 647554
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A. Pazzaglia


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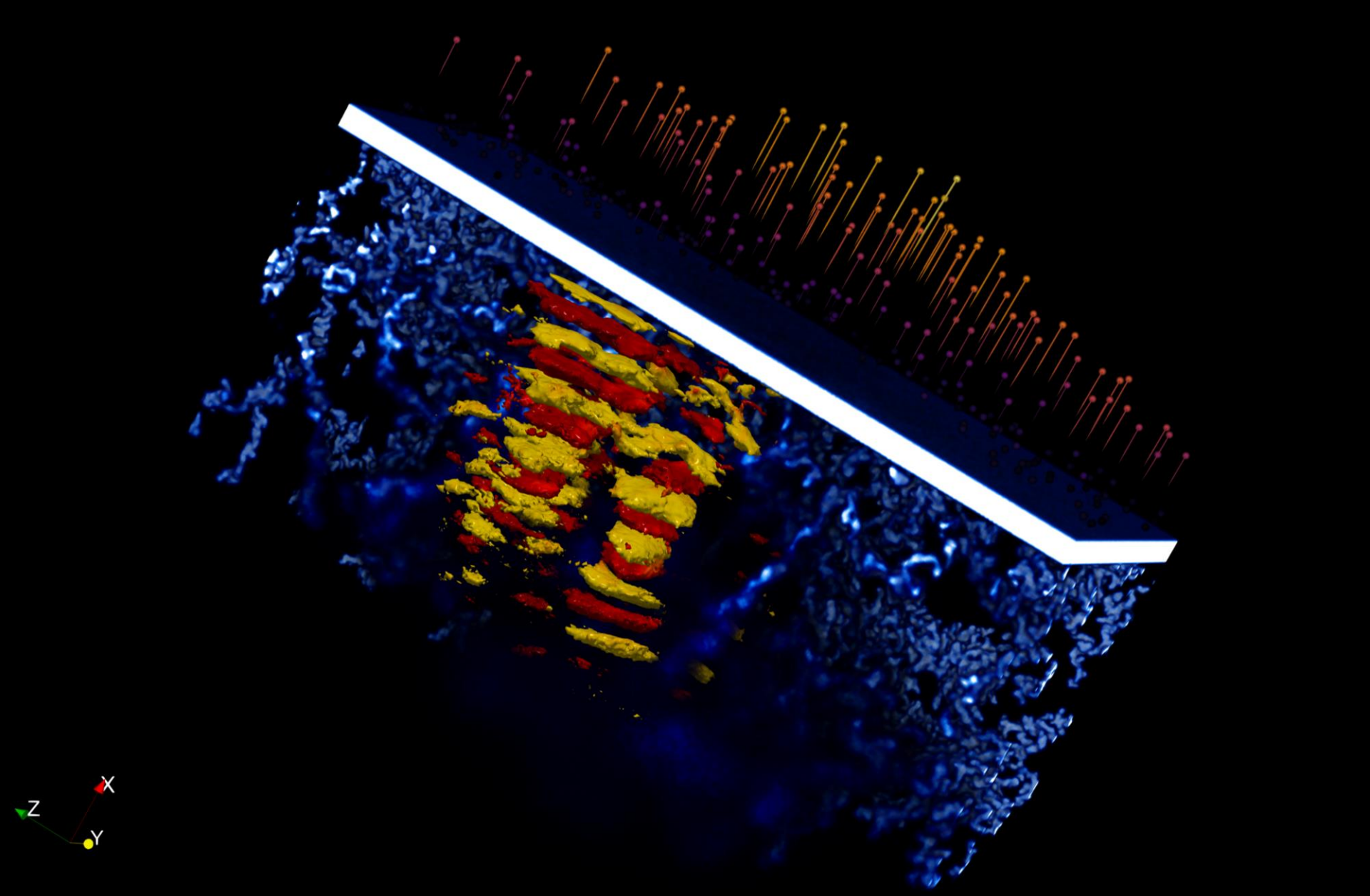
June 2019, Monday 10th to Wednesday 12th



...and thank you for your attention!!