Nuclear Photonics 2018
Brasov Romania

POLITECNICO MILANO 1863

NanoLab
Department of Energy

ERC-2014-CoG No. 647554
ENSURE

Enhanced laser-driven ion sources for nuclear and material science applications

Matteo Passoni
Politecnico di Milano

Nuclear Photonics, Brasov, 28/06/2018

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MILANO 1863

NanoLab
www.nanolab.polimi.it

- Largest university of engineering, architecture and design in Italy.
- More than 40000 students, ~1400 academic staff, 900 doctoral students
- 32 BSc, 34 MSc, 18 PhD programmes.

ENSURE

Exploring the **N**ew **S**cience and engineering unveiled by **U**ltraintense ultrashort **R**adiation interaction with matt**E**r

erc

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DIPARTIMENTO DI ENERGIA

ERC-2014-CoG No.647554

ERC consolidator grant: 5 year project, from September 2015 to September 2020

Goal: To **E**xplore the **N**ew **S**cience and engineering unveiled by **U**ltraintense, ultrashort **R**adiation interaction with matt**E**r

Hosted @ NanoLab, Department of Energy, Politecnico di Milano

Principal investigator:
Matteo Passoni

Team: PI, 2 Associate Professor, 1 Assistant Professor, 3 Post-Docs, 3 PhDs + master students and support from NanoLab people

www.ensure.polimi.it

The ENSURE team at Politecnico di Milano

Matteo Passoni
Associate professor

PI of ENSURE +

ERC-PoC INTER

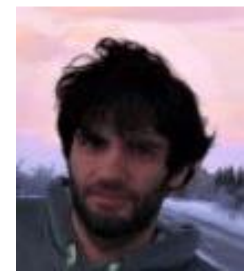
Margherita Zavelani
Associate professor

Andrea Pola
Associate professor

Valeria Russo
Assistant professor

Luca Fedeli
Post-doc

Devid Dellasega
Post-doc



Alessandro Maffini
Post-doc

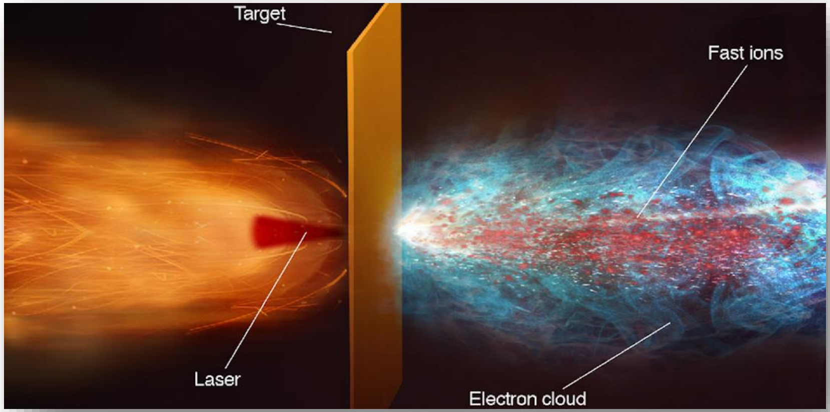
Andrea Pazzaglia
PhD student

Arianna Formenti
PhD student

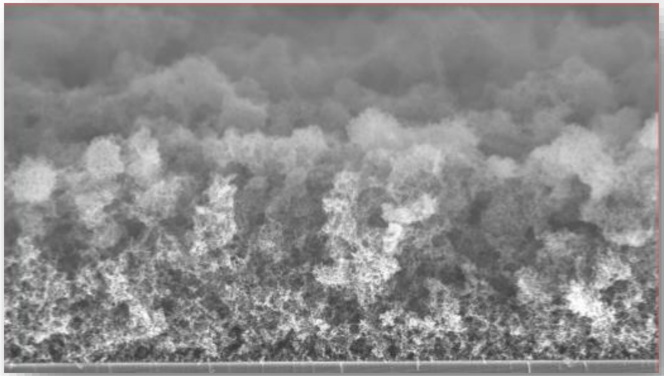
Francesco Mirani
PhD student

Francesca Arioli
Master’s student

ENSURE: Main fields of research



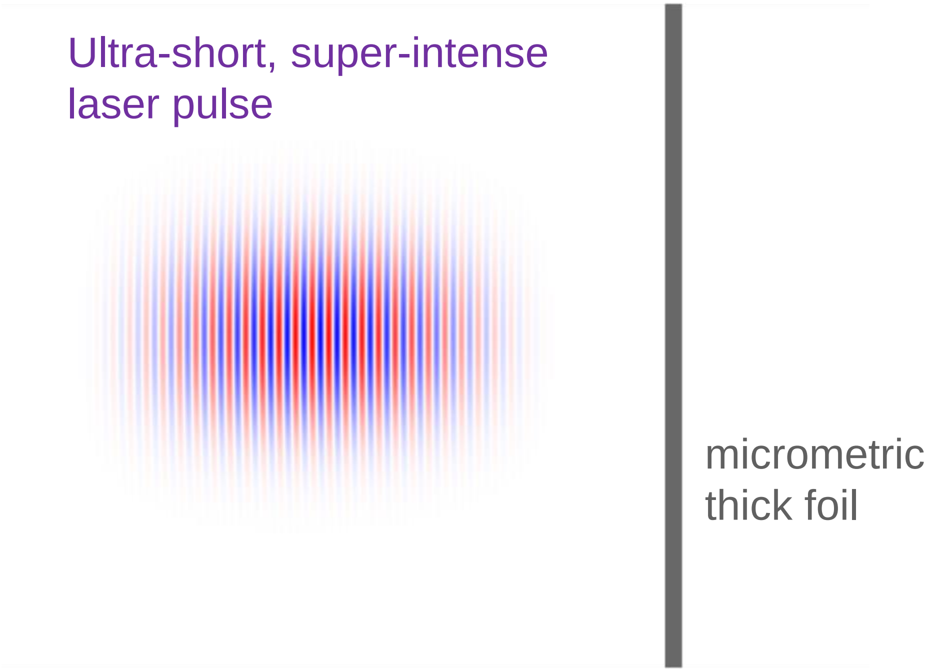
Theoretical & experimental investigation of **laser-driven ion acceleration**



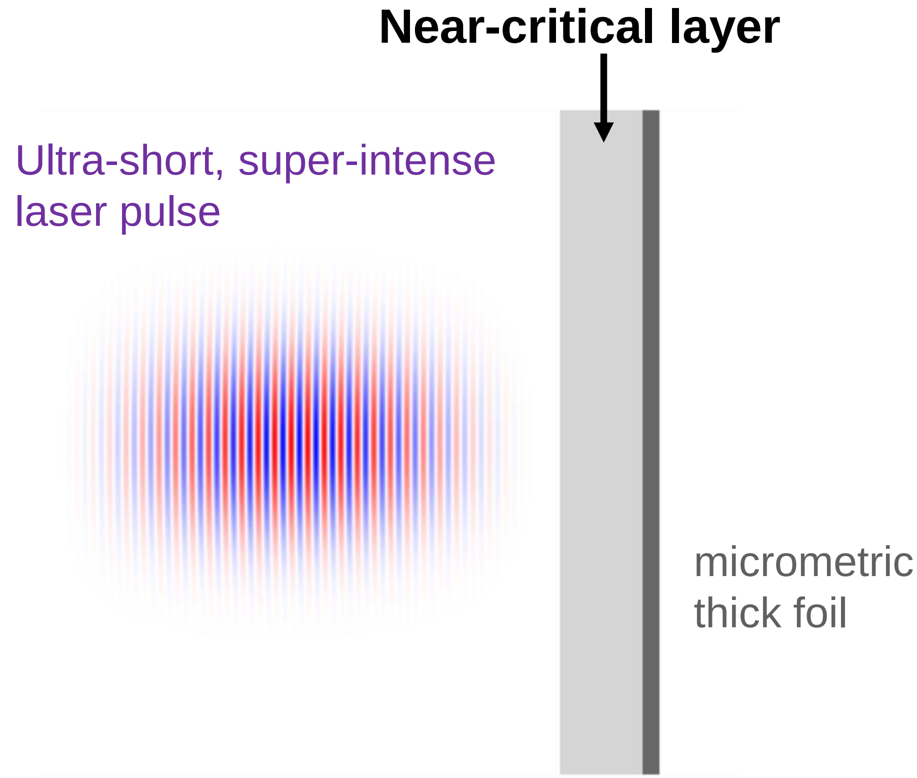
Advanced target production
(low-density foams & multilayer targets)
for laser-plasma interaction experiments

Application of laser-driven ion acceleration
in **material** & **nuclear fields**
(e.g. Compact neutron sources, Laser-driven Ion Beam Analysis)

Target is the key:



Conventional TNSA



Enhanced TNSA

❑ Near-critical layer onto a μm-thick foil

M. Passoni et al. *Phys Rev Acc Beams* **19.6** (2016)

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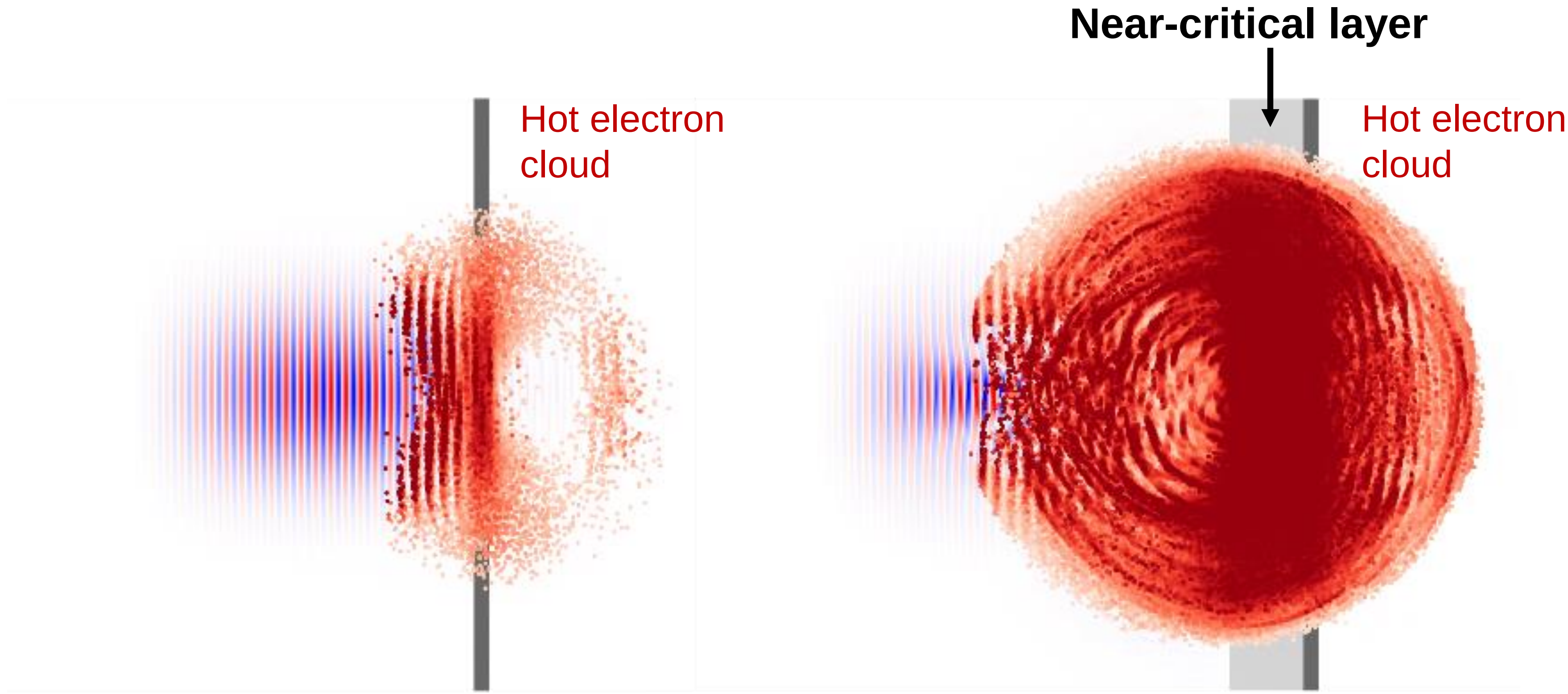

Conventional TNSA **Enhanced TNSA**

- ❑ Near-critical layer onto a μm-thick foil
- ❑ More and hotter relativistic electrons

M. Passoni et al. *Phys Rev Acc Beams* **19.6** (2016)

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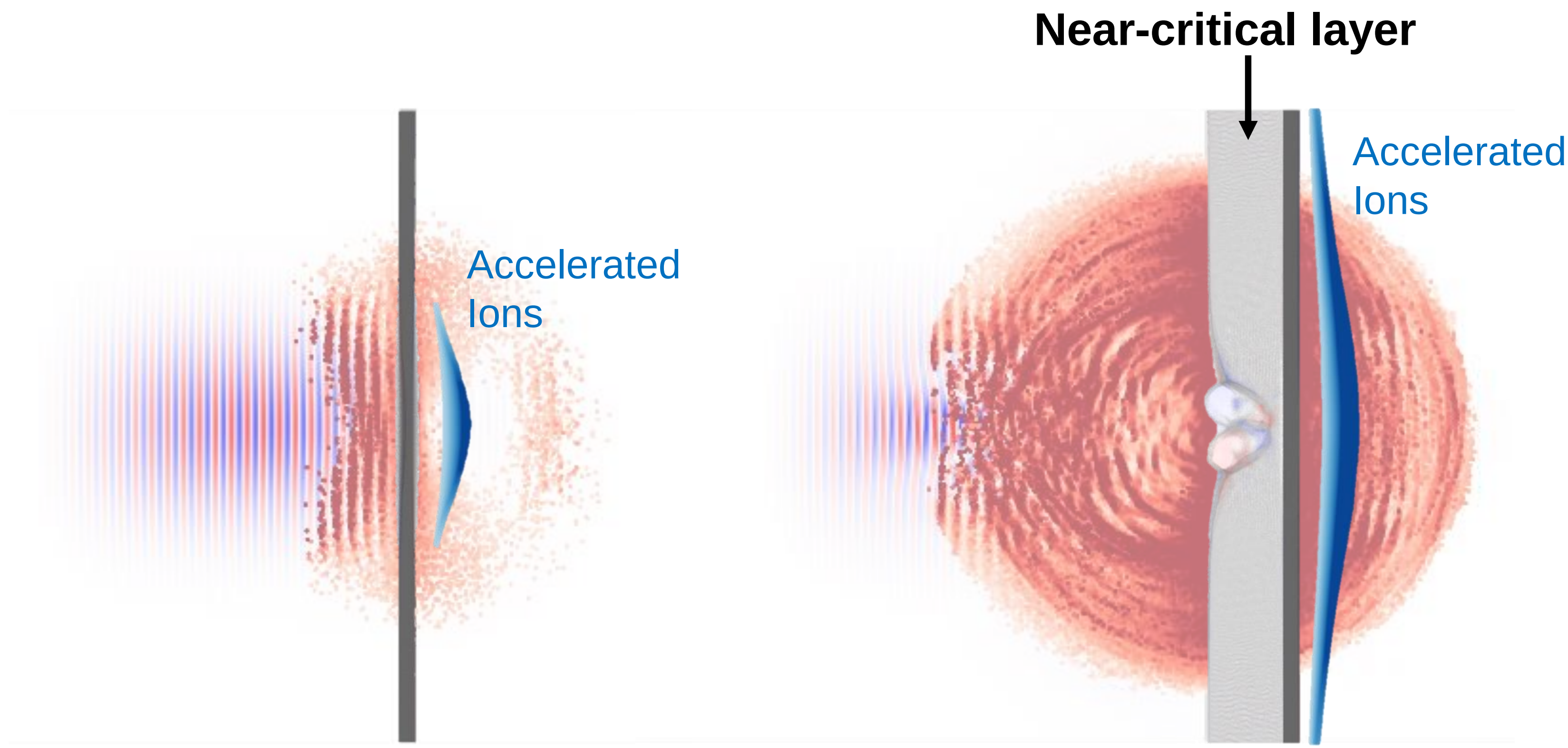


Conventional TNSA

Enhanced TNSA

The target is the key!

- ❑ Near-critical layer onto a μm-thick foil
- ❑ More and hotter relativistic electrons
- ❑ **More ions at higher energy**

M. Passoni et al. *Phys Rev Acc Beams* **19.6** (2016)

Near-critical targets for laser-driven acceleration

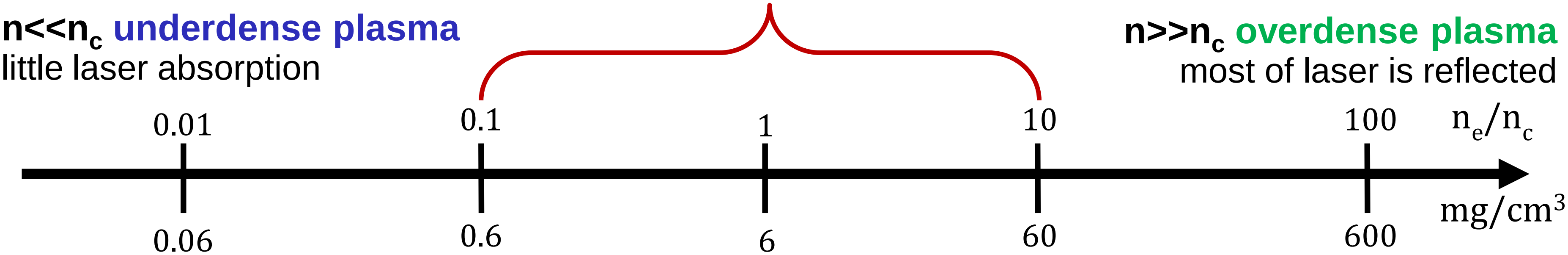
I_{laser}=10^{20} W/cm^2 ⟶ $\mathbf{E}_{laser}$ = 3 x 10^{11} V/m = 50 X $\mathbf{E}_{atomic}$ ⟶ Full ionization ⟶ Plasma!

Plasma critical density: $$n_c = \frac{\pi\, m_e c^2}{e\, \lambda^2}$$ $n_c \approx 6\ \mathrm{mg/cm^3}$ (@ λ=800 nm)

n ≈ n_c near critical plasma
strong laser-plasma coupling

n<<n_c underdense plasma
little laser absorption

n>>n_c overdense plasma
most of laser is reflected

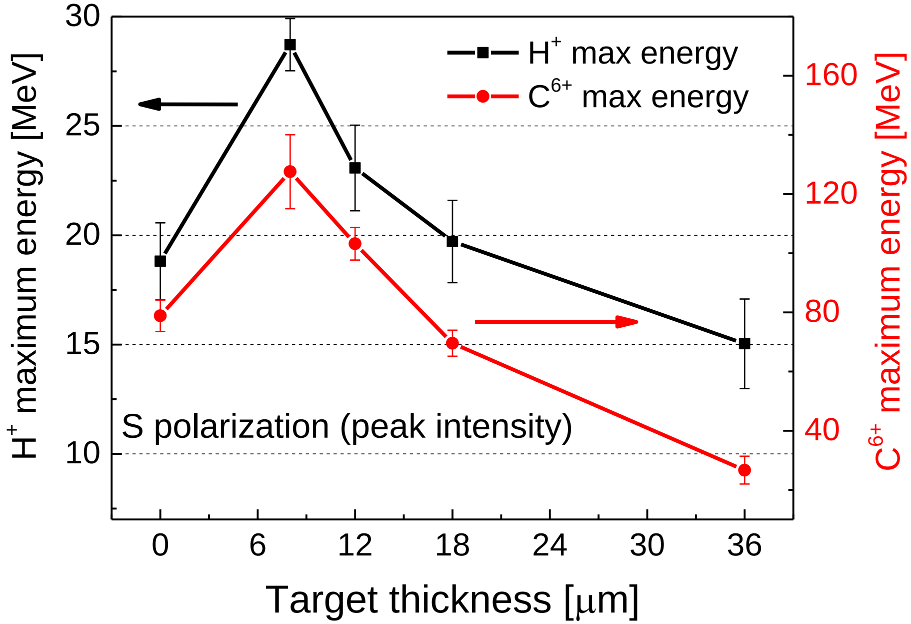


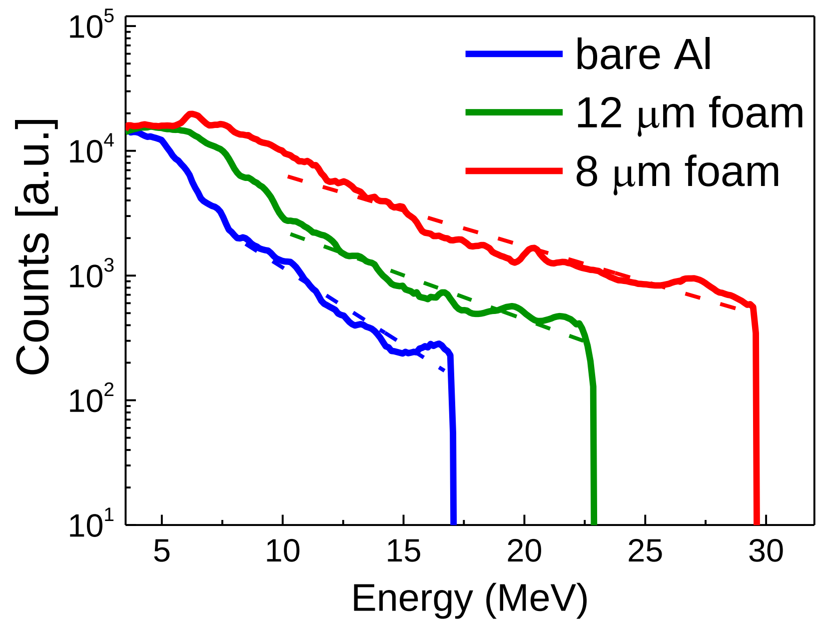
Ion acceleration @ PULSER (GIST)

in collaboration with: I. W. Choi, C. H. Nam et al.

Role of target properties (s-pol, ~ 7 J, 3×10^{20} Wcm^{-2}, 30° inc. angle)

- **nearcritical foam thickness**: Al (0.75 µm) + foam (6.8 mg/cm^3, **0-36 µm**)





- There is an **optimum** in near critical layer **thickness**
- **Maximum** proton **energy enhanced** by a factor ~ **1.7**
- **Number** of proton **enhanced** by a factor ~ **7**

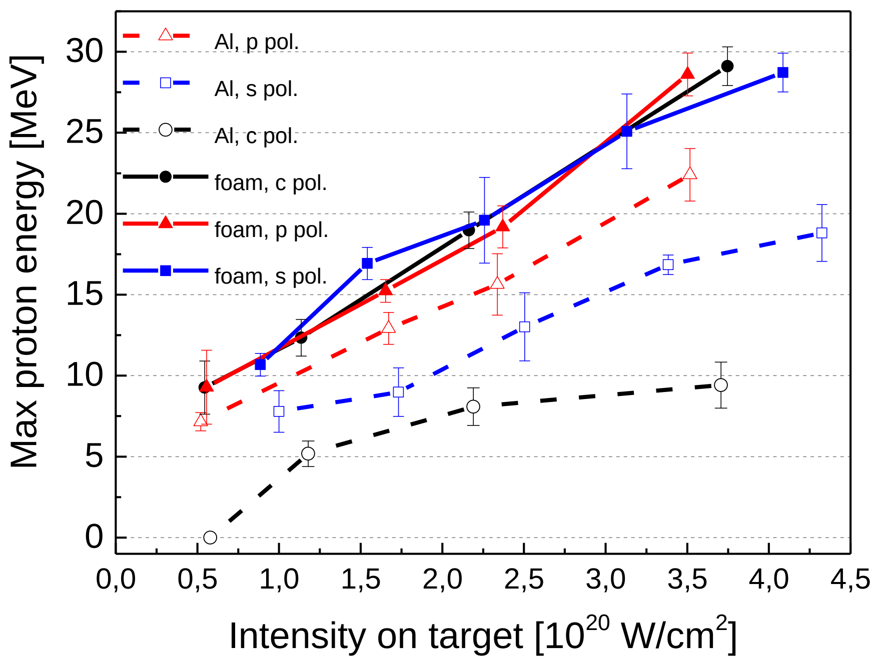
M. Passoni et al., *Phys. Rev. Accel. Beams* **19**, (2016)
I. Prencipe et al., *Plasma Phys. Control. Fus.* **58** (2016)

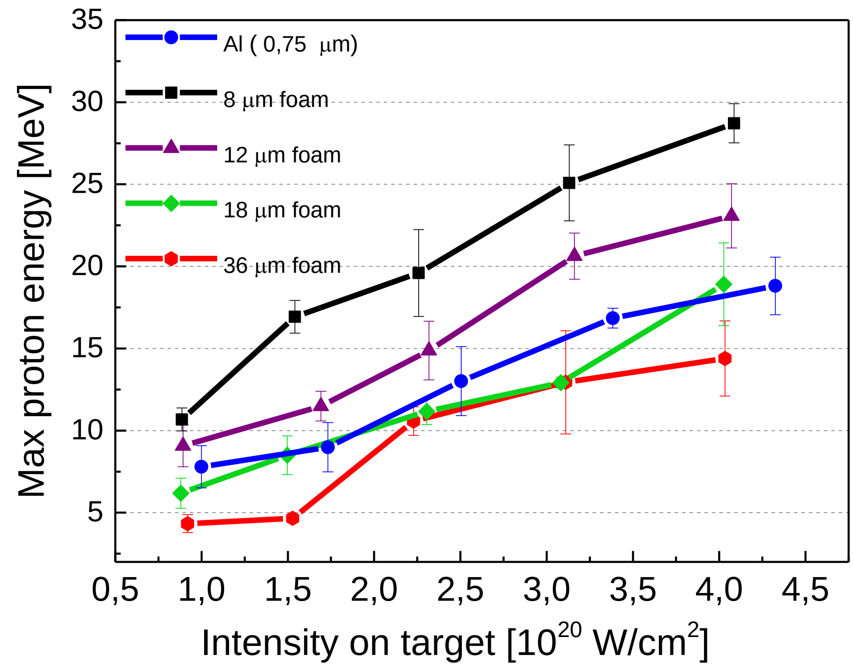
Ion acceleration @ PULSER (GIST)

in collaboration with: I. W. Choi, C. H. Nam et al.

Role of pulse properties Al (0.75 µm) + foam (6.8 mg/cm^3, 8 µm)

- pulse **intensity**
- pulse **polarization**: s, p and circular polarization





Dependence on **polarization**:

- strong for Al foils
- reduced for foam targets

- foam vs Al: **volume vs** surface interaction
- irregular foam surface: polarization **definition**
- role of target **nanostructure**

Ion acceleration @ DRACO 150 TW
(preliminary data!)

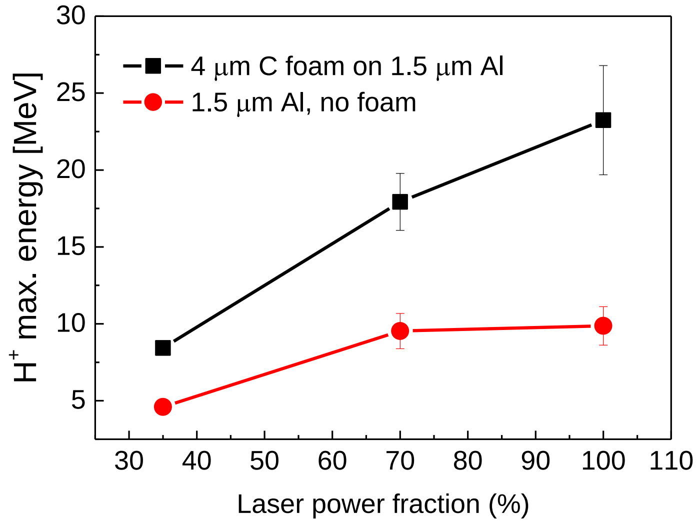
in collaboration with:
I. Prencipe, T. Cowan, U. Schram et al.

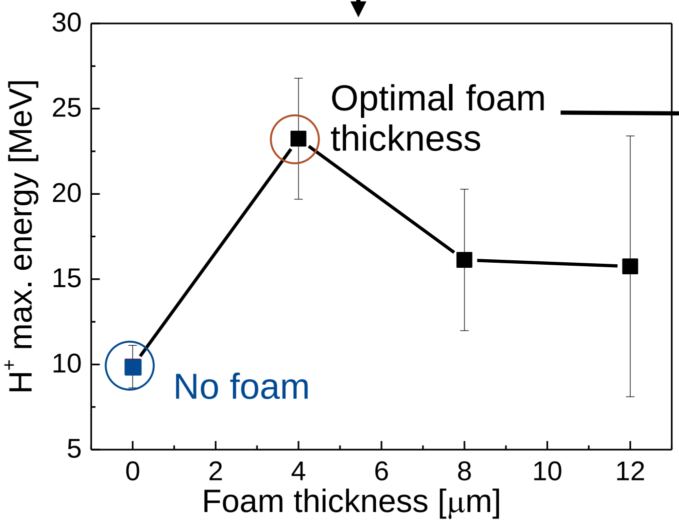
Laser parameters @ Draco (HZDR, Dresden)

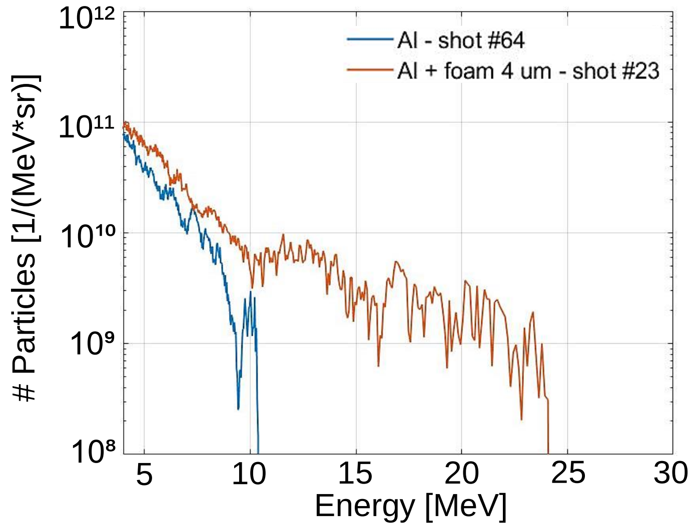
- Energy on target = 2 J
- Intensity = up to 5 x 10^{20} W/cm^2
- Angle of incidence = 2°

Foam PLD parameters

- F = 2.1 J/cm^2
- P = 1000 Pa Ar
- d_{ts}= 4.5 cm
- Substrate = Al 1.5 μm
- Foam thickness = 4, 8, 12 μm







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n ≈ n_c near critical plasma

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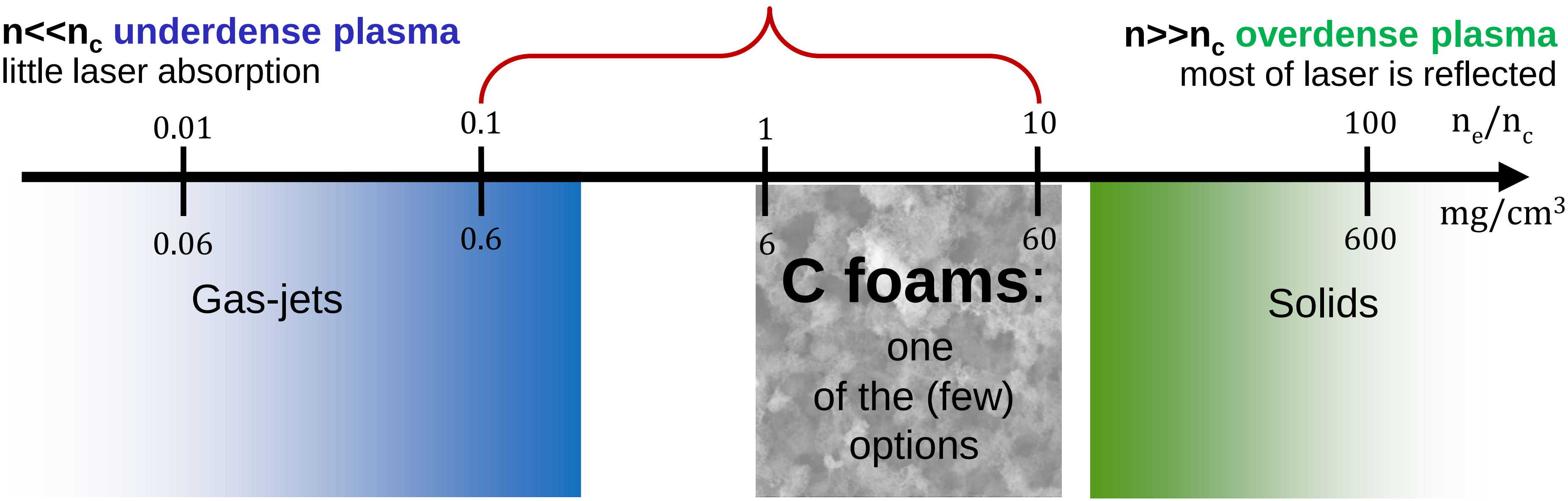
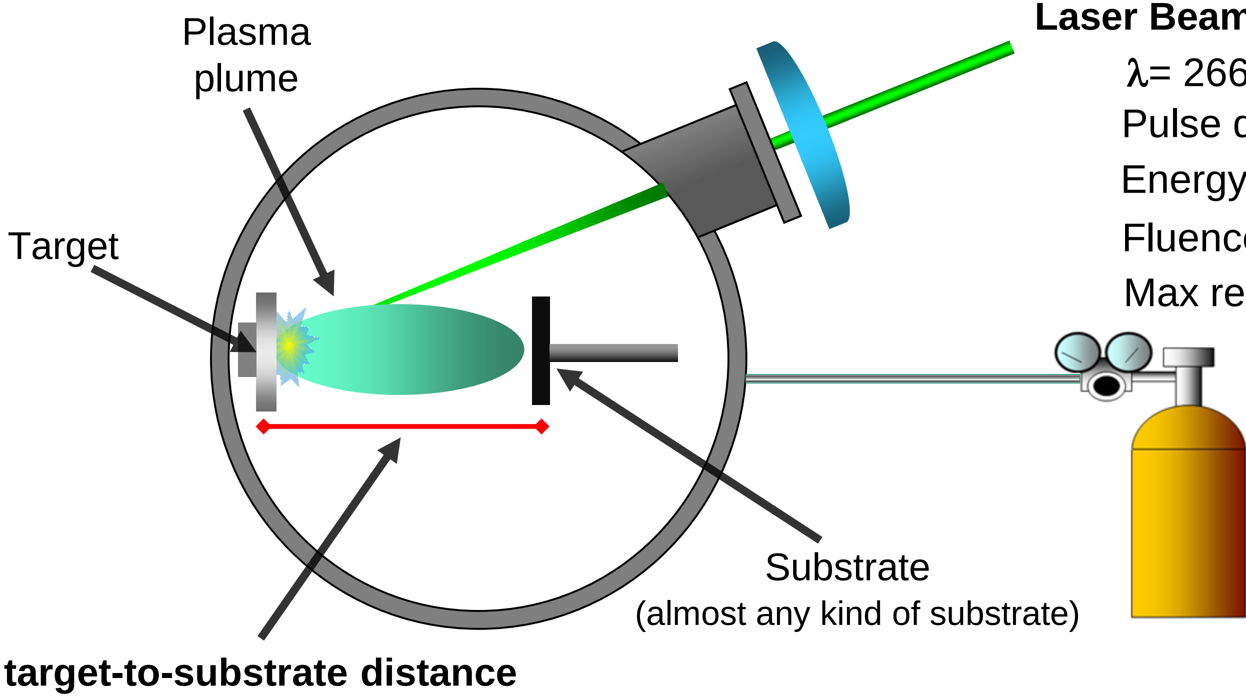
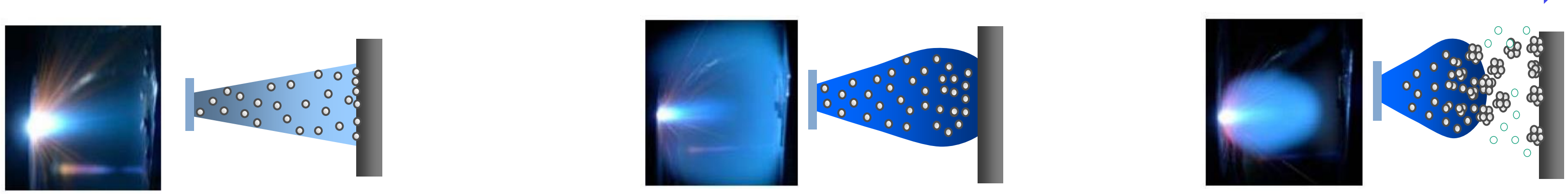


How to produce C foams: ns Pulsed Laser Deposition (PLD)



Background Gas

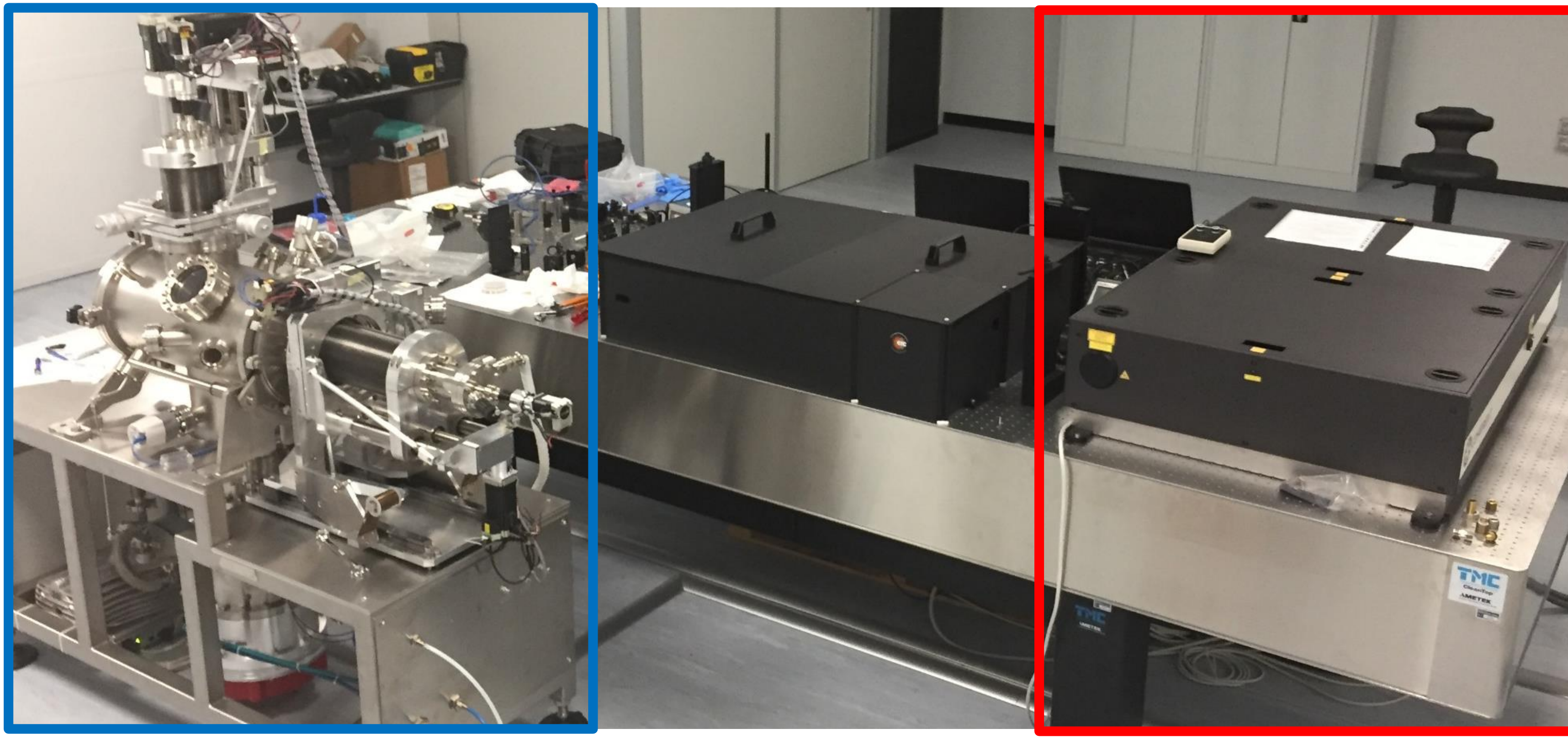
- Inert (He, Ar..)
- Reactive (O_2)



“atom by atom” deposition

“Nanoparticle” deposition

New experimental facilities @ Nanolab



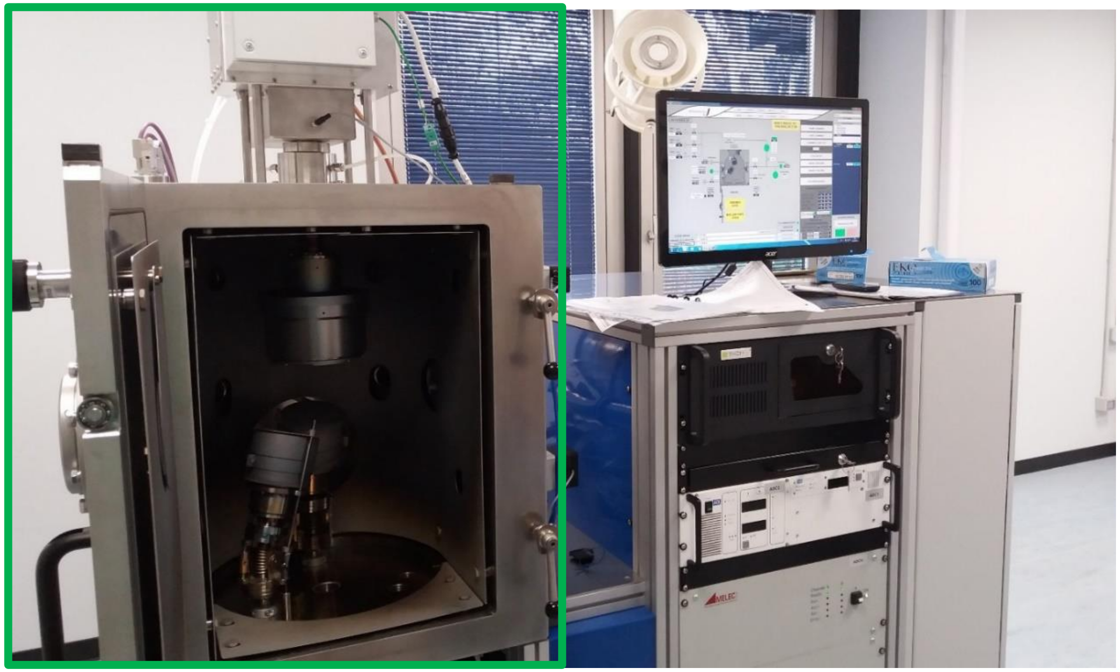
fs-PLD interaction chamber

- ❑ PLD mode + Laser processing
- ❑ up to 4 targets
- ❑ Upstream + downstream pressure control
- ❑ Fast substrate heater
- ❑ Fully automated software

Coherent Astrella ™

- ❑ Ti:Shappire λ=800 nm
- ❑ Ep > **5 mJ**
- ❑ Pulse duration **< 100 fs**
- ❑ Peak Power > 50 GW
- ❑ Rep Rate = 1000 Hz

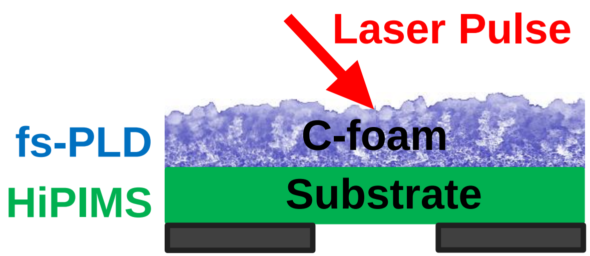
New experimental facilities @ Nanolab



High Power Impulse Magnetron Sputtering (HiPIMS):

- Peak power density = 10^3 W/cm^2
- Peak current density = 1 – 10 A/cm^2
- Two cathodes, multi-elemental targets
- Fully automated software

Combined fs-PLD & **HiPIMS** deposition techniques to fully **control target preparation**!



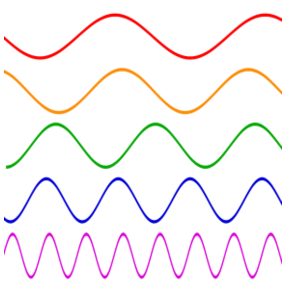
Foam property control with ns-PLD

Nano-scale
- Crystalline structure
- Composition

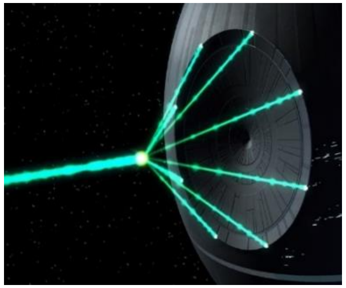
Micro-scale
- Average density
- Morphology
- ….

Macro-scale
- Uniformity
- Thickness profile

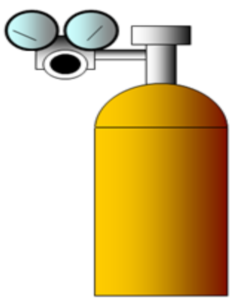
Laser Wavelength



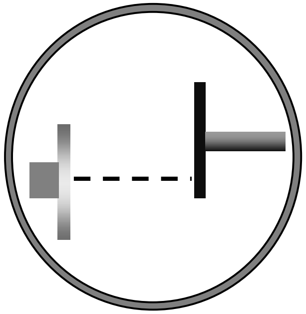
Laser Fluence



Gas pressure



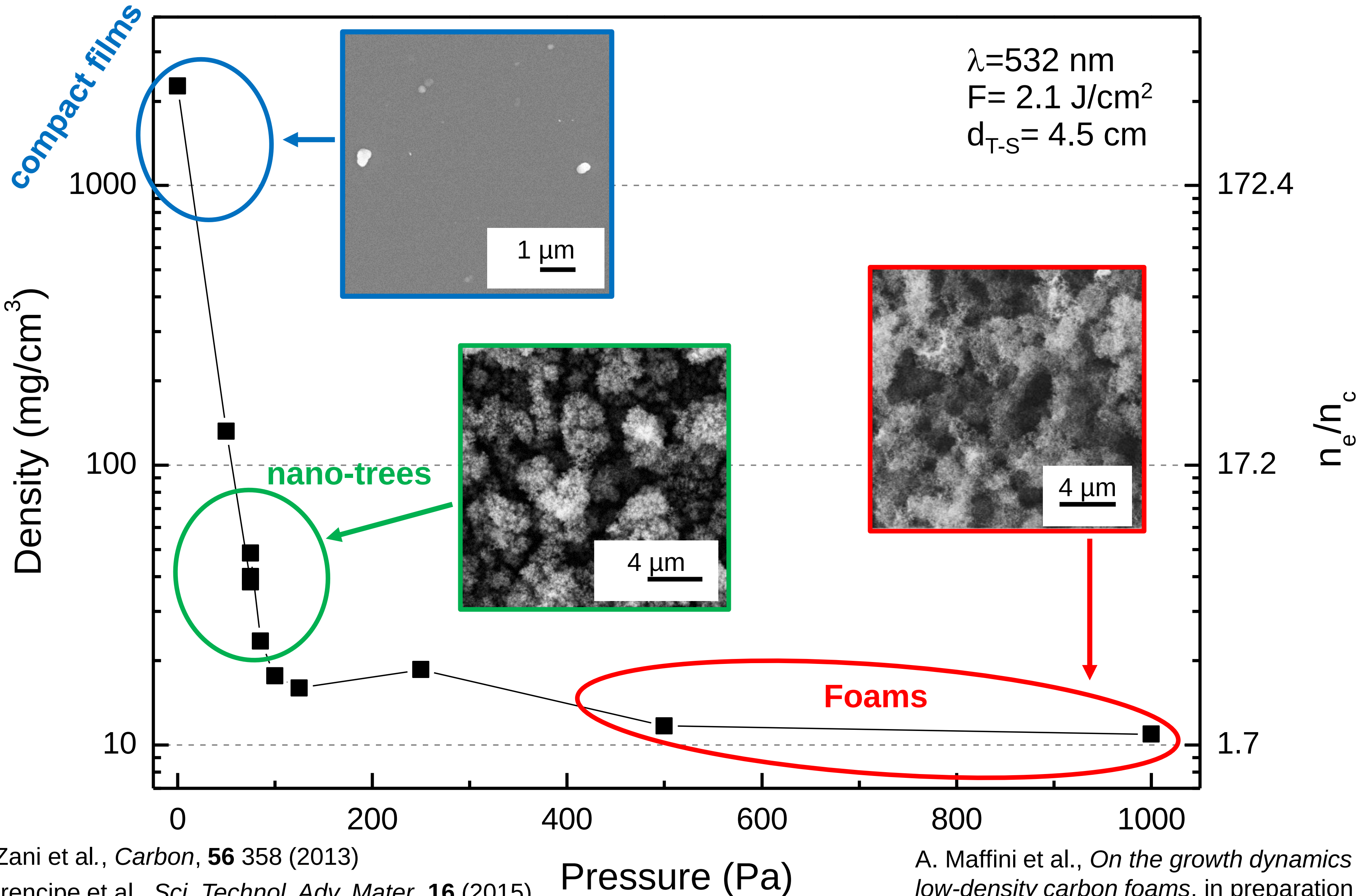
Geometry



Deposition time

ns-PLD process parameters

How to produce carbon foams



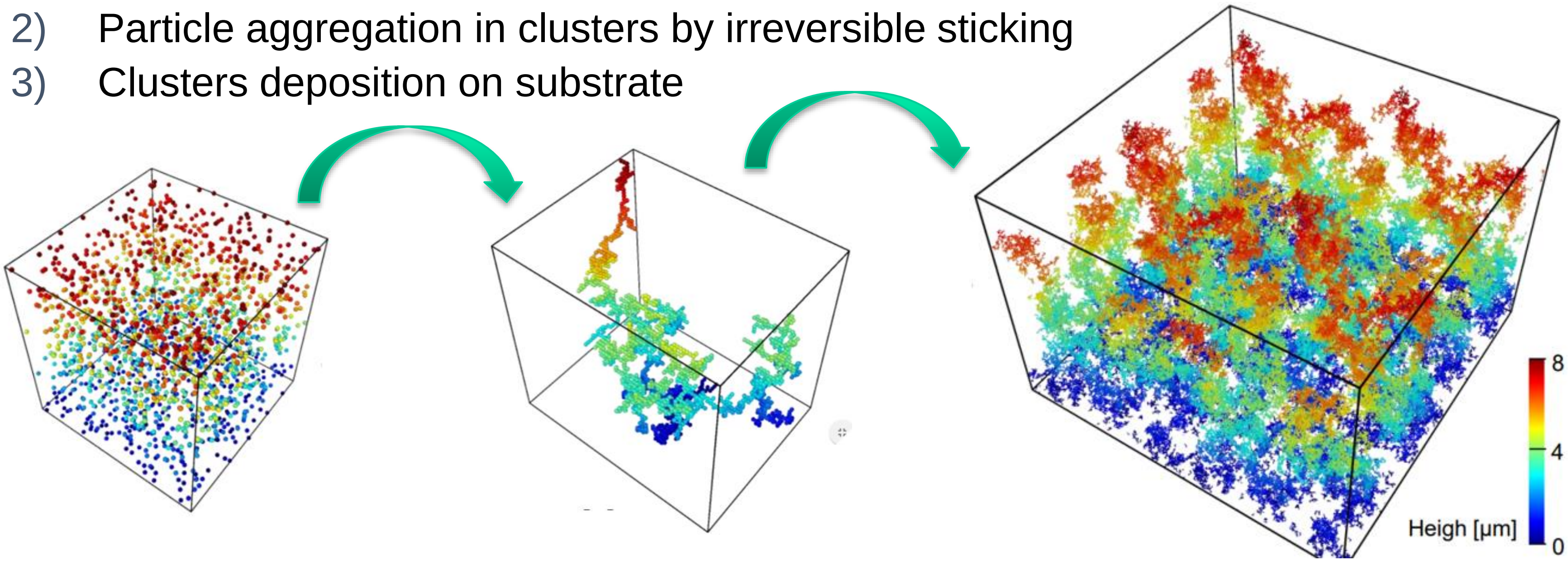
A. Zani et al., *Carbon*, **56** 358 (2013)
I. Prencipe et al., *Sci. Technol. Adv. Mater*. **16** (2015)

A. Maffini et al., *On the growth dynamics of low-density carbon foams*, in preparation

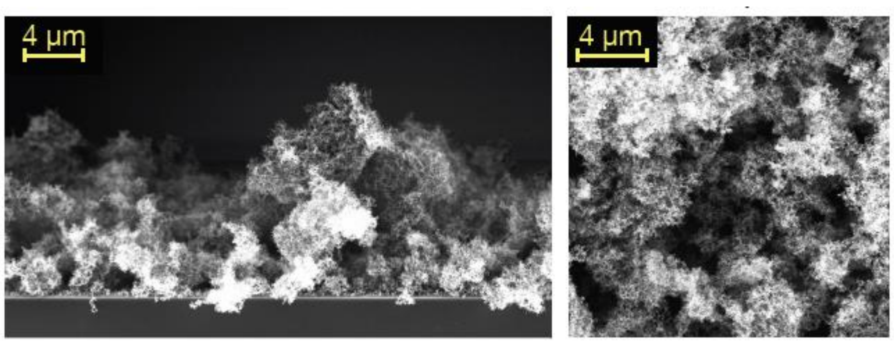
Aggregation model to study the foam growth

Diffusion-Limited Cluster-Cluster Aggregation (DLCCA):

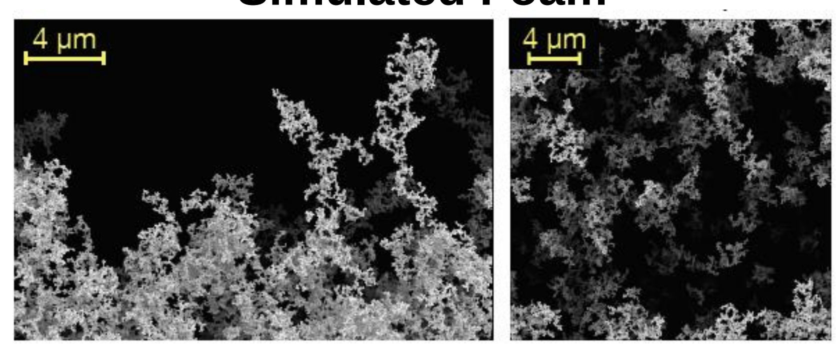
1) Brownian motion of particles
2) Particle aggregation in clusters by irreversible sticking
3) Clusters deposition on substrate



Real Foam



Simulated Foam

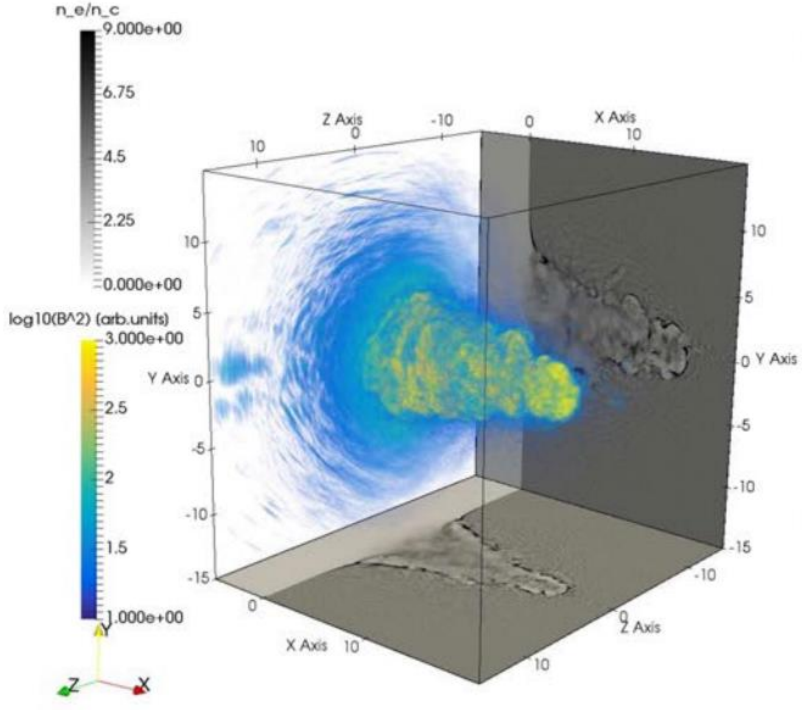


Particle In Cell (PIC) Simulations

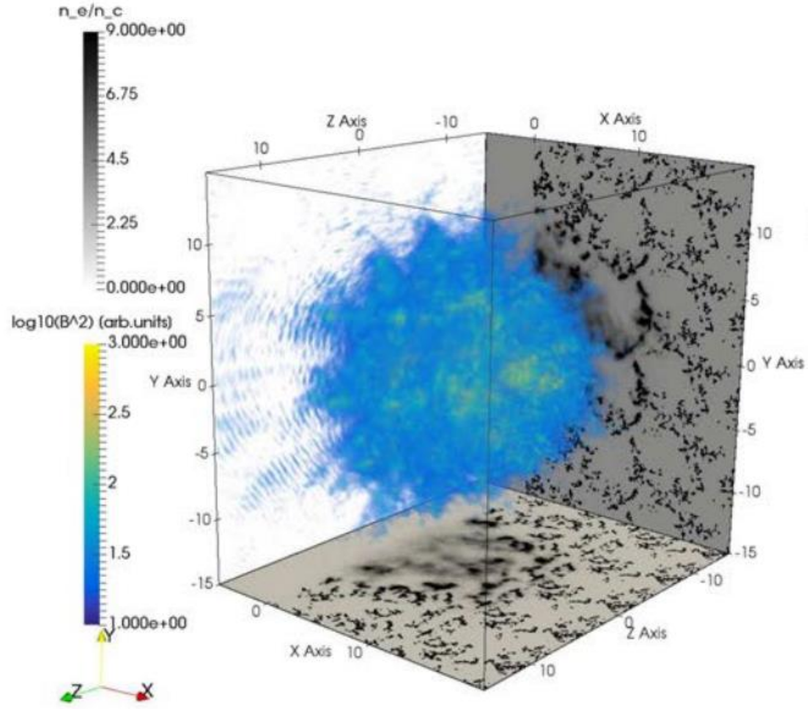
Well established and powerful tool to **study laser plasma interaction**

Inclusion of the **nanostructure morphology** to properly model physical processes

- With **homogeneous** foam



- With **DLCCA** foam

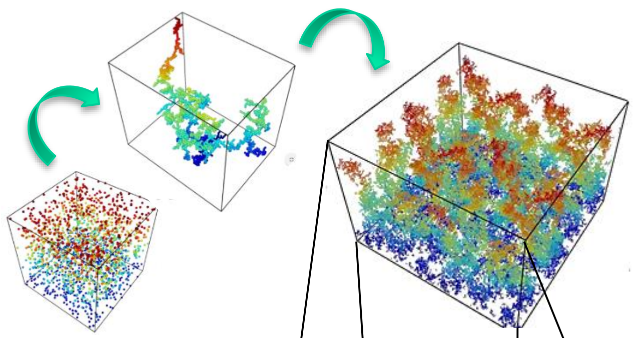


L. Fedeli et al. Scientific Reports, **volume 8**, Article number: 3834 (2018)

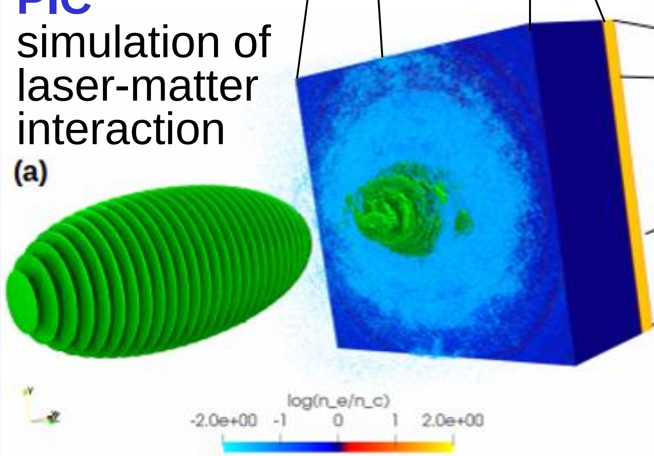
Integrated numerical simulation of laser-ion app

A novel tool to study laser-driven ion sources for **nuclear** and **material science**

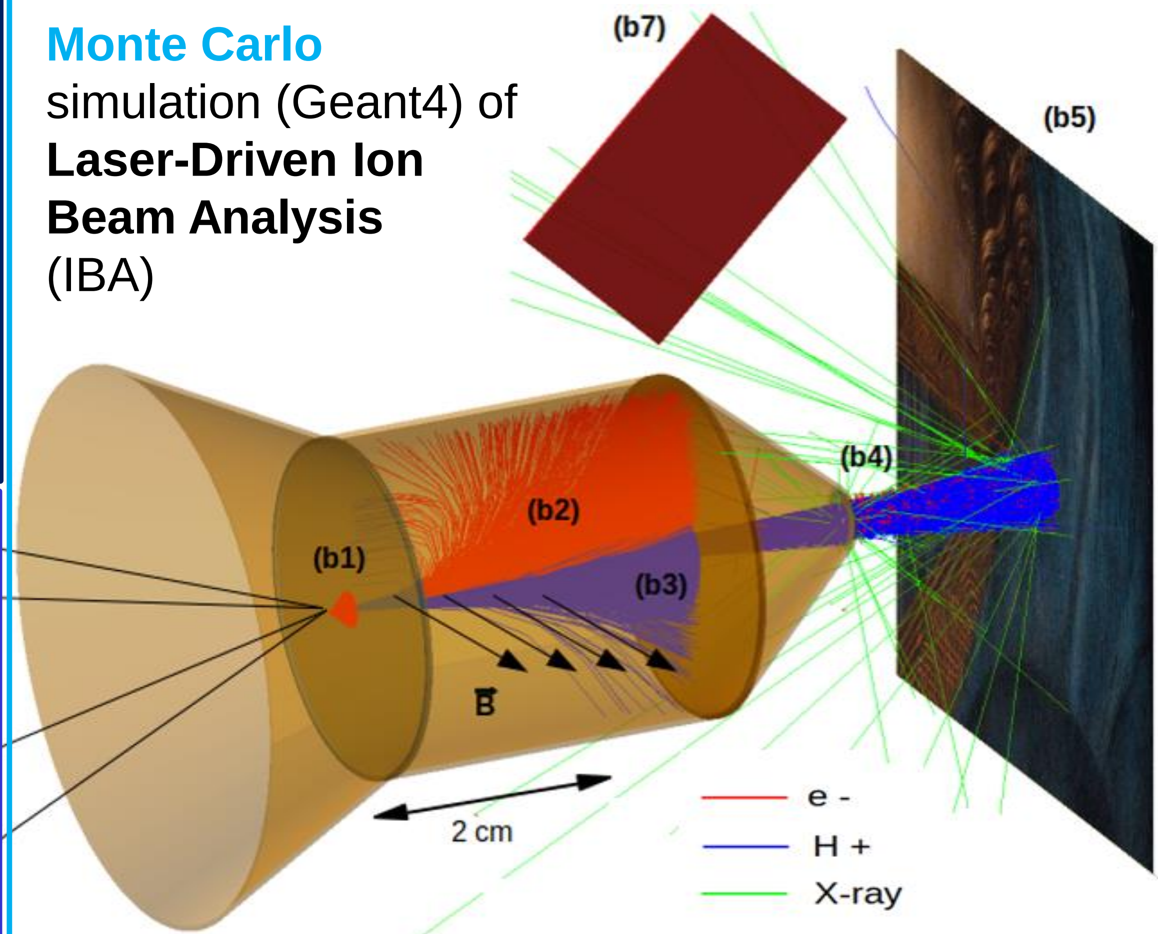
DLCCA simulation of foam aggregation



PIC
simulation of laser-matter interaction



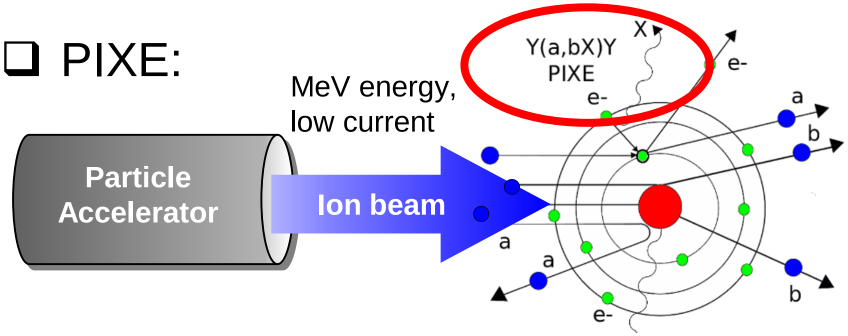
Monte Carlo simulation (Geant4) of **Laser-Driven Ion Beam Analysis** (IBA)



M. Passoni et al., *Scientific Reports* (2018), under review

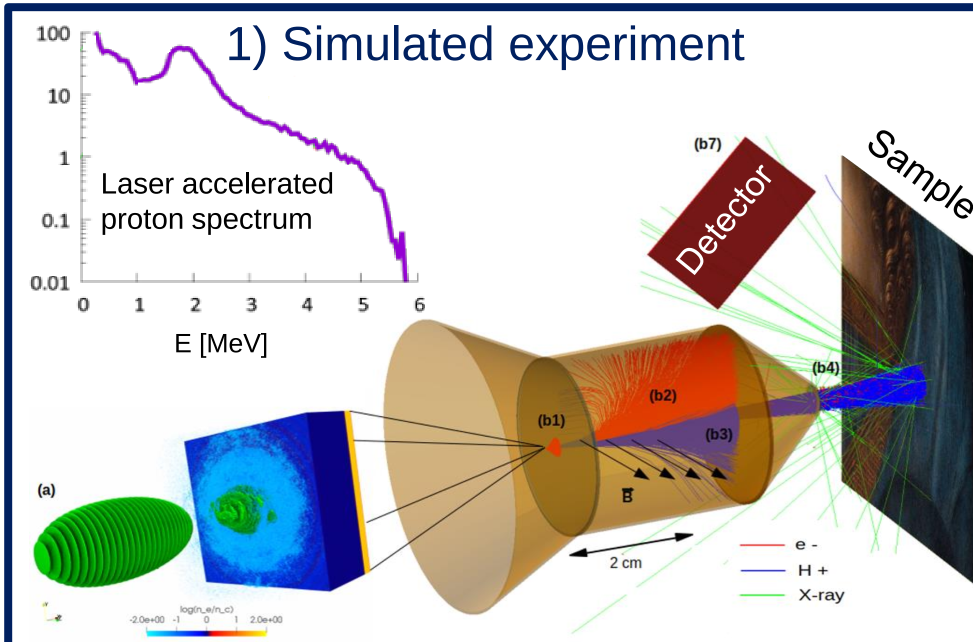
Laser-driven Particle Induced X-ray Emission (PIXE)

- ❑ PIXE:

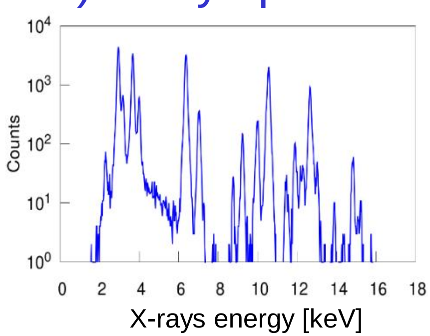


- ❑ Laser-driven PIXE:
  - ✓ **Unconventional features** of ion beam (broad spectrum, tunable energy, ns bunch duration)
  - ✓ **Cheaper, portable** PIXE setup
- ❑ Commercial codes not ok for laser PIXE
  - ✓ Ad-hoc code developed

1) Simulated experiment

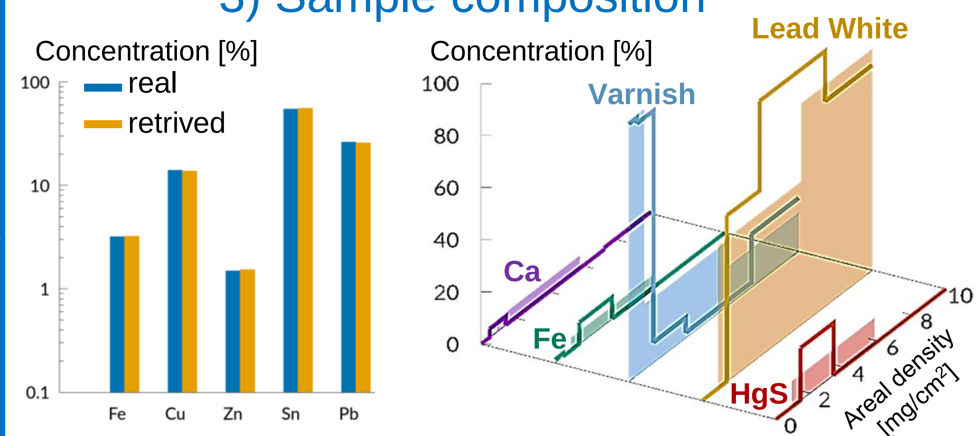


2) X-ray spectra

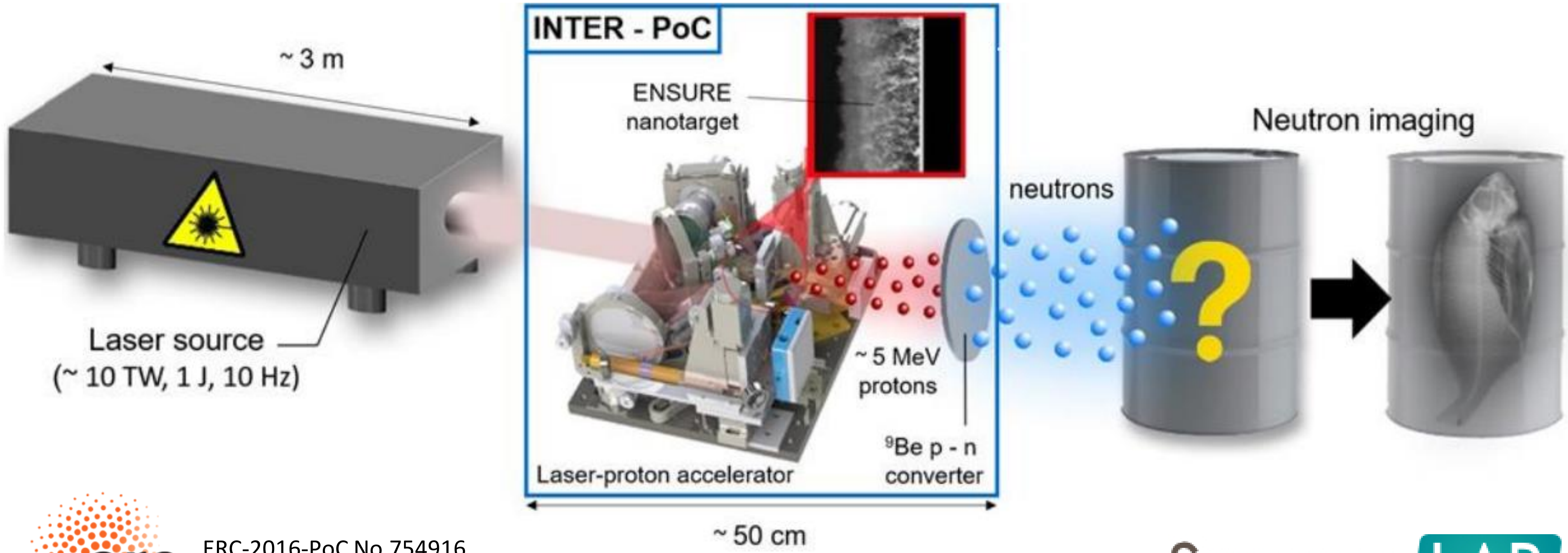


Dedicated **software** to process x-ray data

3) Sample composition



Towards portable neutron sources

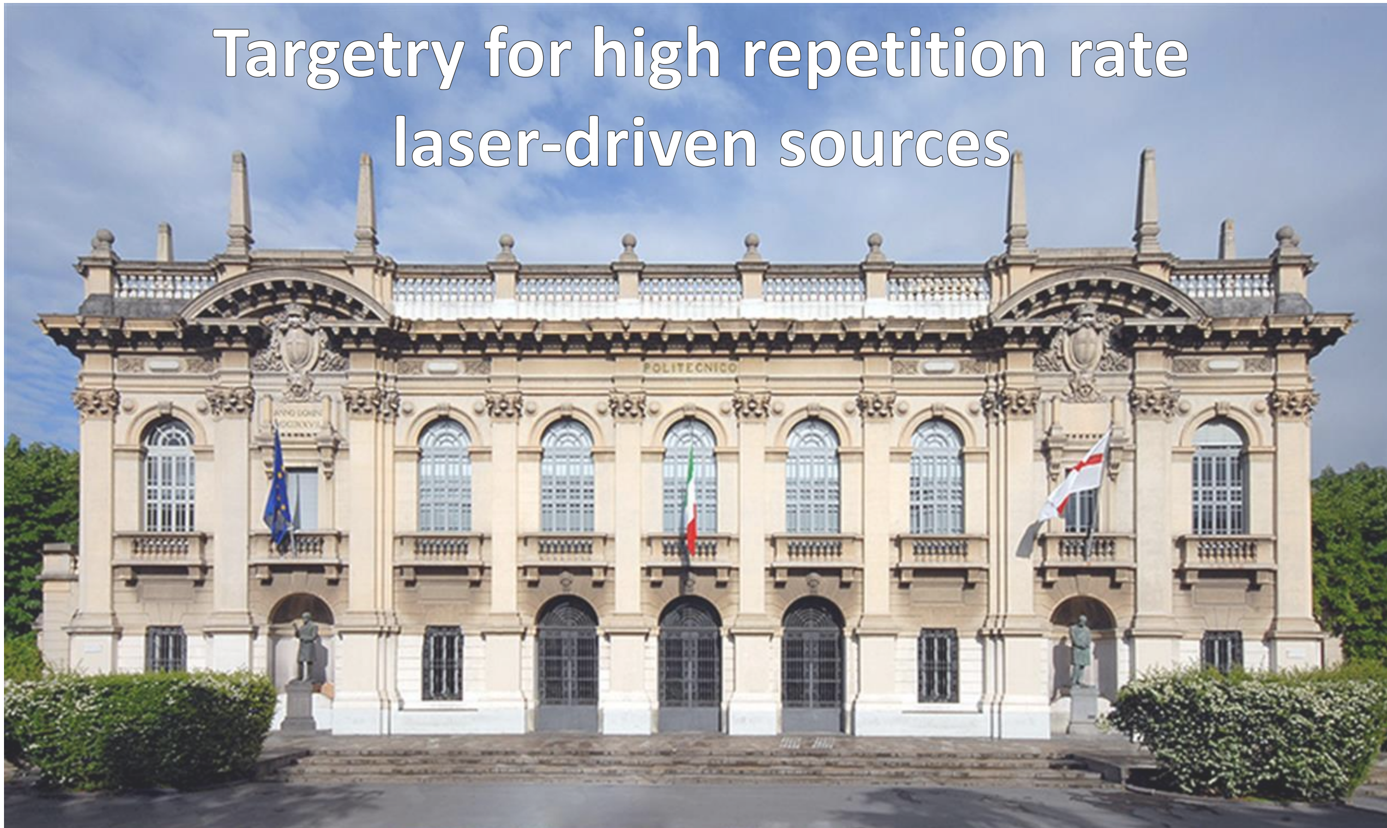


ERC-2016-PoC No.754916
INTER

- ❑ Compact neutron sources for material characterization
  - fast-neutron spectroscopy
  - neutron radiography
- ❑ Preliminary studies with coupled PIC - Monte Carlo simulations
- ❑ Strong collaboration with industrial partners
- ❑ **See Maffini (P39), Mirani (P46) posters!**

A. Tentori, *MSc thesis in Nuclear Engineering* (2018)
F. Arioli, *MSc in Nuclear Engineering*, in preparation

Preliminary announcement of the **4th Targetry Workshop**



Monday 10th - Wednesday 12th, **June 2019**

Politecnico di Milano, **Milano, Italy**

Contact: matteo.passoni@polimi.it

targetry suppliers network

DELIVERING TARGETRY EXCELLENCE

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