POLITECNICO
MILANO 1863

TARG4

4th Targetry for High Repetition Rate Laser-Driven Sources Workshop

NanoLab
DEPARTMENT OF ENERGY

erc
ERC-2014-CoG No. 647554
ENSURE

Production of optimized multi-layer targets for enhanced laser driven ion acceleration

Francesco Mirani
Politecnico di Milano

TARG4, Milan, 10/06/2019

Laser-driven Ion Sources

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10s TW Class Lasers

- Compactness
- Stability
- High repetition rate

Applications in **material science** (e.g. **Ion Beam Analysis, neutron generation end radioisotope production**)

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- Liquid targets
- Cryogenics jets
- Solid targets

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Laser-driven Ion Sources

10s TW Class Lasers

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- ❖ Stability
- ❖ High repetition rate

- ❖ Liquid targets
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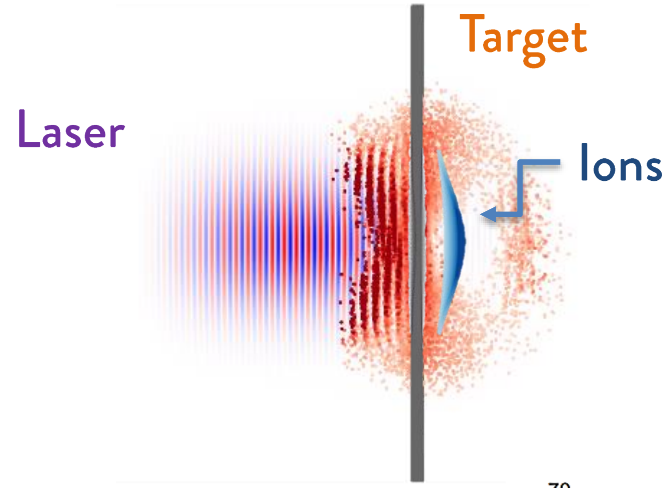
- ❖ Solid targets

TNSA

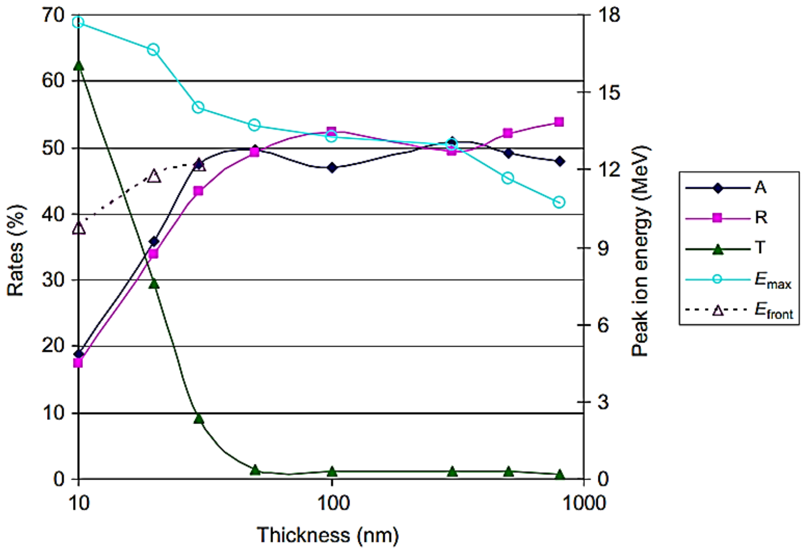
Applications in **material science** (e.g. **Ion Beam Analysis**)

Target Normal Sheath Acceleration (TNSA)



- I > 10^19 W/cm^2
- thickness ~ **100s nm – some um**
- ↓ t → higher energies

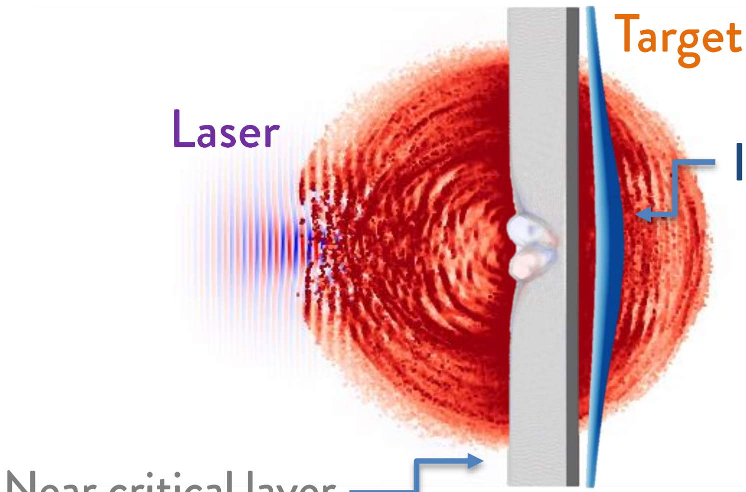
The target is the key!



E. Lefebvre et al., New J. Phys. 12 (2010), no. 4, 045017.
T. Ceccotti et al., Phys. Rev. Lett. 99 (2007), no. 18, 185002.

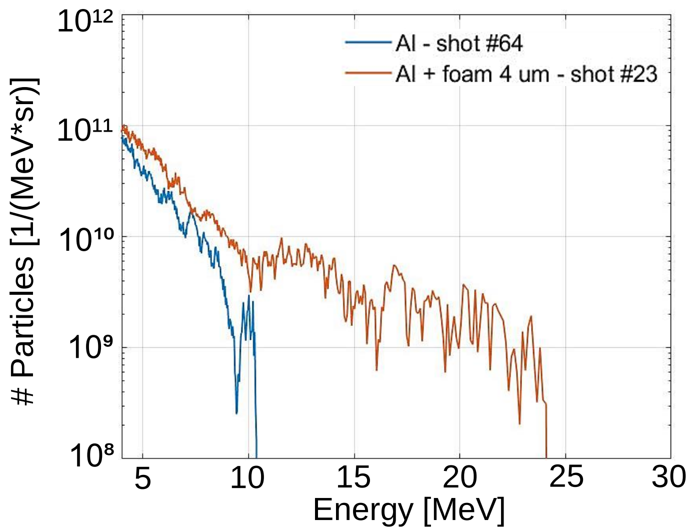
A. Macchi et al., Rev. Mod. Phys. 85(2), 751 (2013).

Enhanced Target Normal Sheath Acceleration (TNSA)



- Hotter relativistic e-
- More ions at **higher energies**

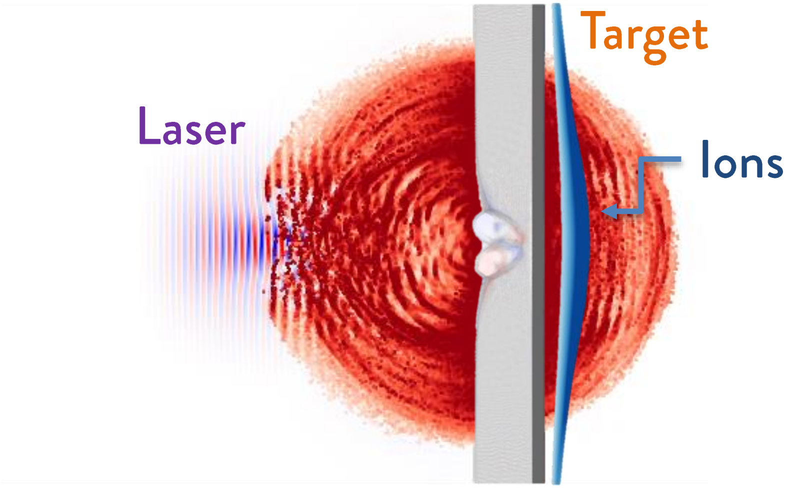
The target is the key!



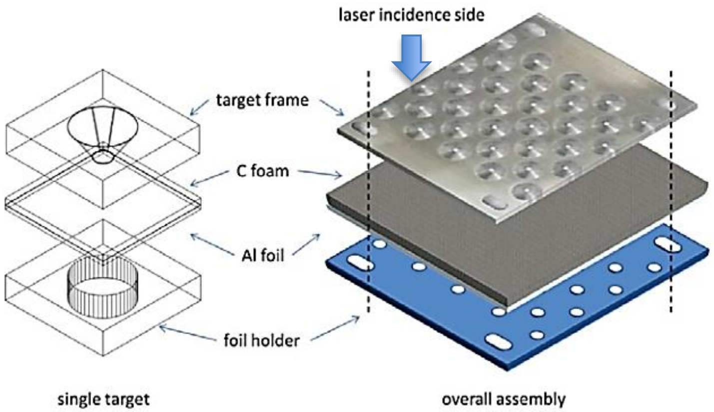
A. Macchi et al., Rev. Mod. Phys. 85(2), 751 (2013).

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

Enhanced Target Normal Sheath Acceleration (TNSA)



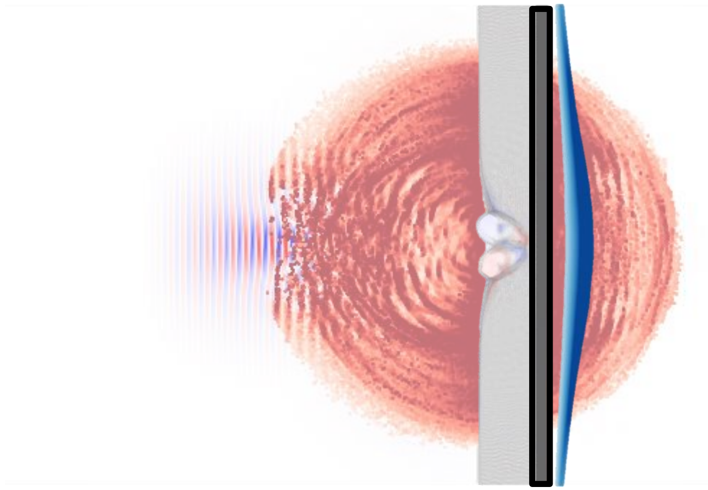
Standard substrates...



- Rolling -> local **thickness uncertainty** (± 30 %)
- **Limited** number of **thicknesses**
- Deformation while attaching

Affecting hole by hole **reproducibility**!

Direct deposition of the target on the holder!

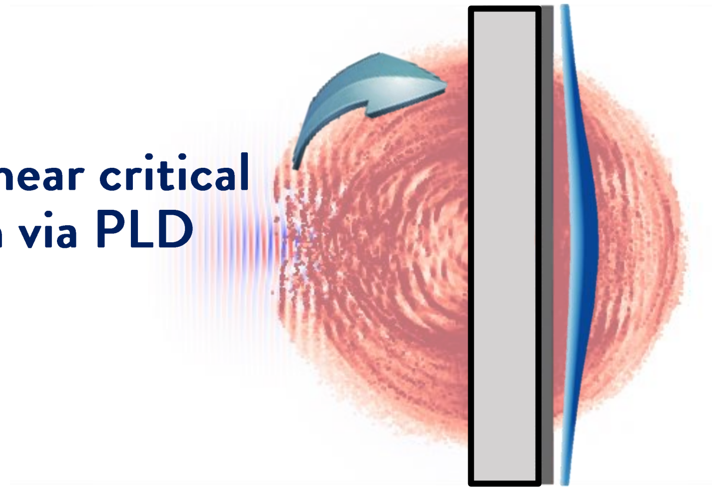


Many possible improvements on target!

- ✓ **Tuning thicknesses** (um –nm)
- ✓ Thickness **uniformity (light tight)**
- ✓ **Multilayer film** & **Multielemental** composition
- ✓ Film growth on frame → **no attaching problems**

Direct deposition of the target on the holder!

Deposition of near critical carbon foam via PLD



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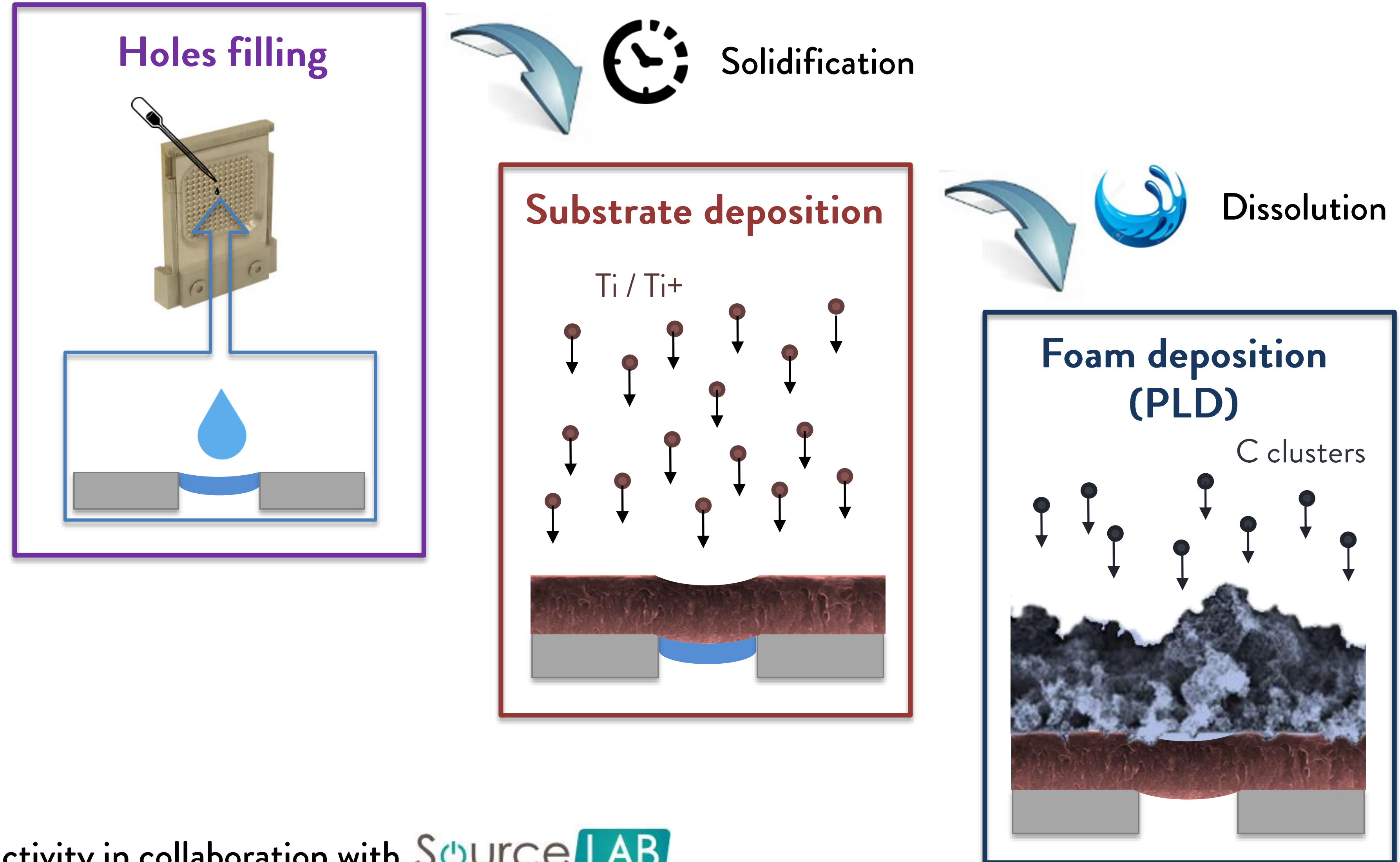
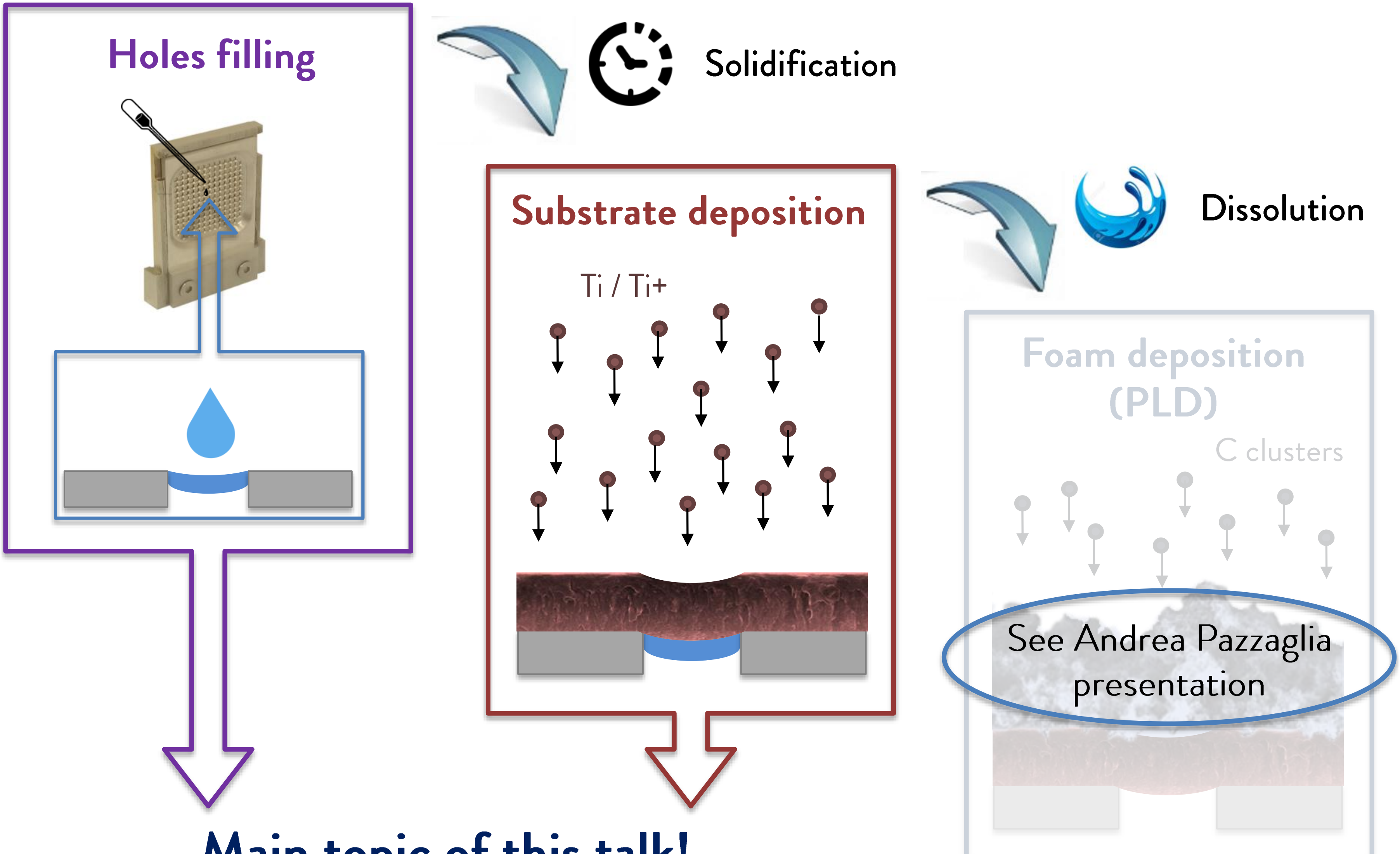
Step-by-step target fabrication



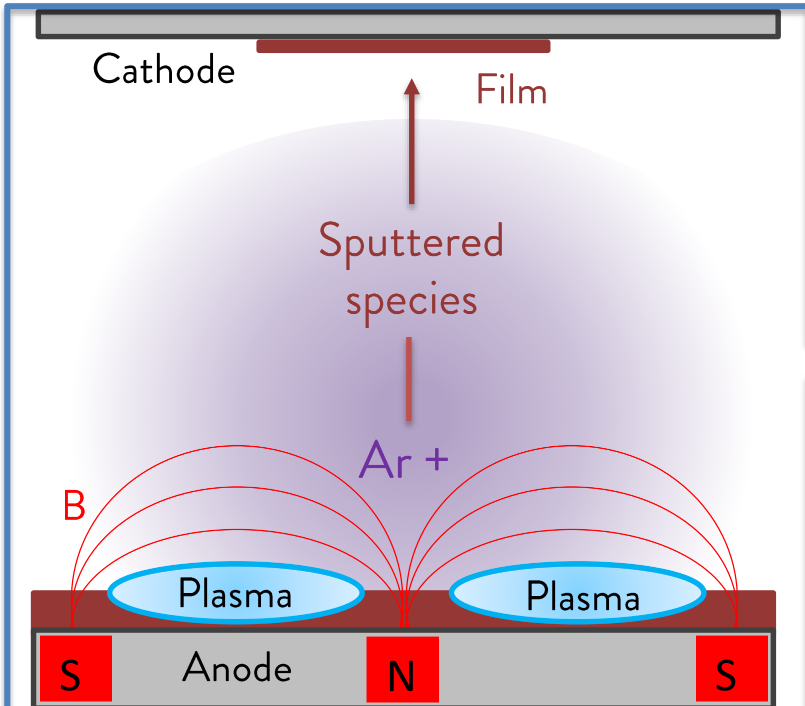
Activity in collaboration with SourceLAB

Step-by-step target fabrication

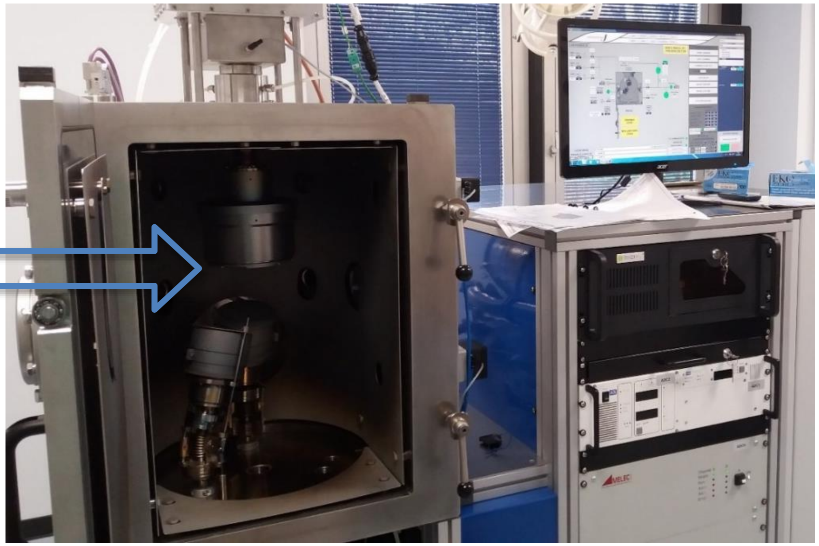


Main topic of this talk!

Magnetron Sputtering



Experimental facility @ Nanolab

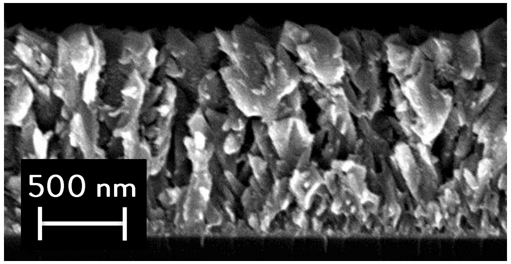


- Physical Vapour Deposition (**PVD**)
- **Magnetic field** to concentrate the plasma on sputtering target.
- Well established **industrial technique.**
- **Many target materials** & **substrates.**
- **Different** types of **power sources.**

Magnetron Sputtering

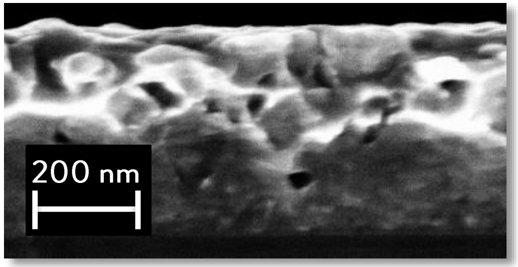
Direct Current (DC) Magnetron Sputtering

- Mean power density ~ 1 W/cm2
- Ionized fraction ~ 1 %
- Columnar growth:



High Power Impulse Magnetron Sputtering **(HiPIMS)**

- Peak power density ~ 10^3 W/cm2
- Ionized fraction > 50 %
- Compact morphology:



- **Uniform** deposition on **large surfaces.**
- Film thickness from **few nm** up to **several μm.**
- **Tunability of** density, morphology and mechanical **properties.**

K. Sarakinos et al., Surf. and Coat. Technol. 204 (2010), no. 11, 1661 – 1684.

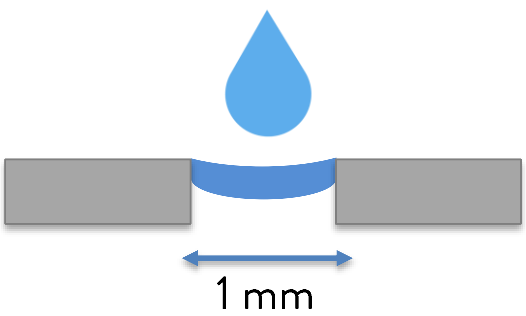
Holes filling

Filling material requirements:

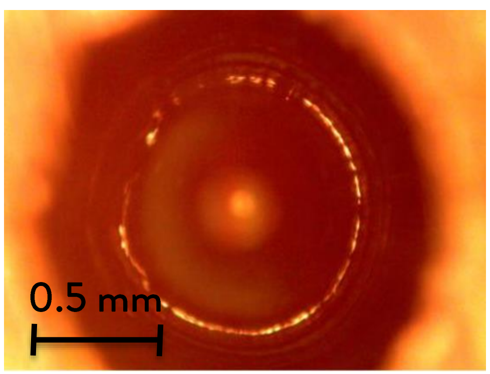
- High solubility value
- Fast solidification
- Heat resistance
- Low viscosity in solution

best compromise →

Sucrose!



Solidification:

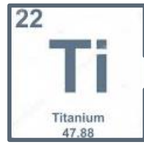


~ 1 hours in **vacuum** → **Reveal** the presence of **air bubbles**

~ 3 hours on **heating** plate (90 °C) → **Accelerate** the **crystallization** process

Substrate Production & Characterization

Selected material:



- Good mechanical & thermal properties
- Good corrosion resistance

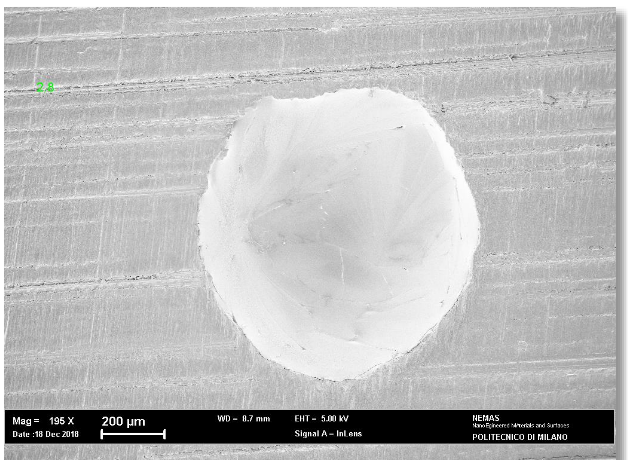
Substrate Production & Characterization

Selected material: 22 Ti Titanium 47.88

- Good mechanical & thermal properties
- Good corrosion resistance

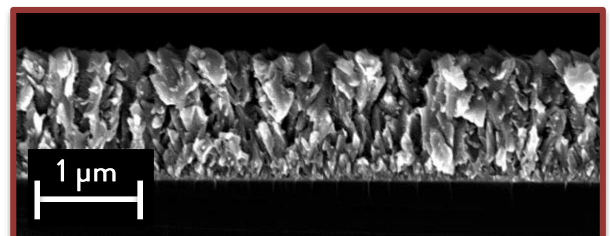
DC

Sucrose Structural integrity



Compactness of the film

$\rho \approx 0.60\ \rho_{bulk}$



Fast failure after removal of sucrose!

Substrate Production & Characterization

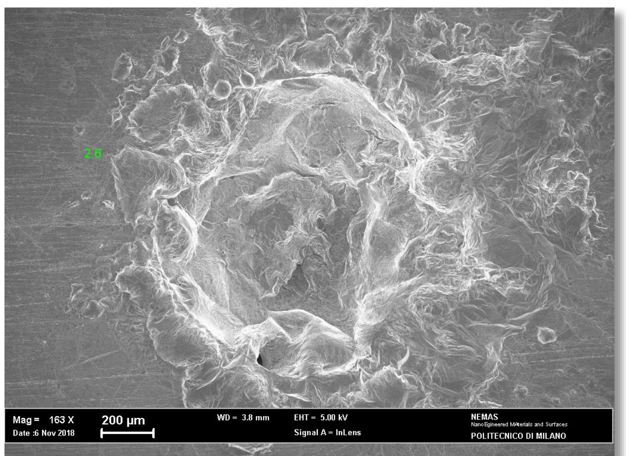
Selected material: 22 Ti Titanium 47.88 →
- Good mechanical & thermal properties
- Good corrosion resistance

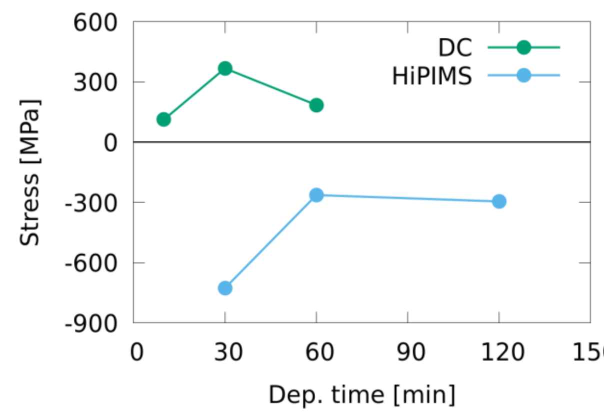
HiPIMS

Sucrose Structural integrity → Presence of a strong stress state 

↓

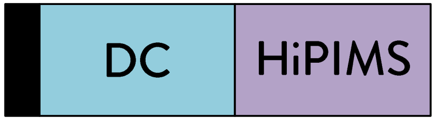
Wafer curvature measurement





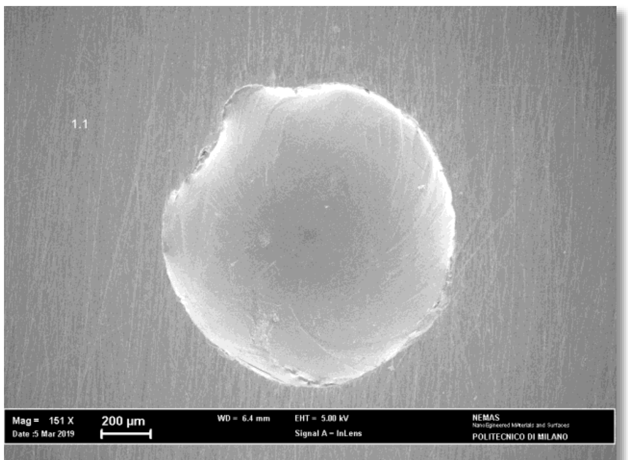
E. Chason, et el., *J. Appl. Phys.* 119 (2016), no. 14, 145307.

Combine DC & HiPIMS deposition techniques in a bi-layer structure!



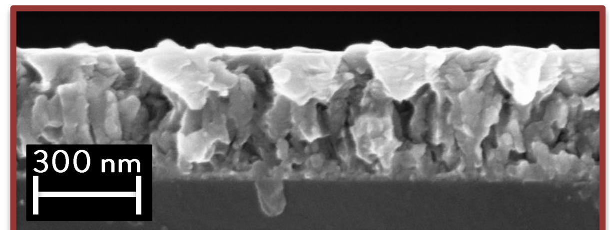
DC: **50 – 75 %** of the thickness
HiPIMS: **25 -50 %** of the thickness

✓ Sucrose Structural integrity



✓ Compactness of the film

$\rho \approx 0.80\ \rho_{bulk}$



Success after sucrose removal!

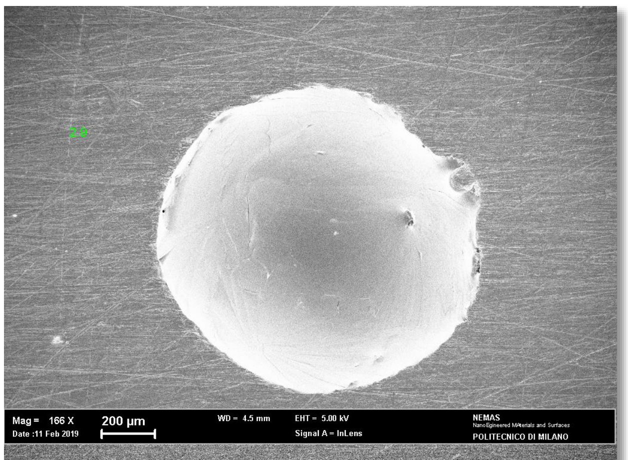
Substrates production between **300 - 400 nm** thickness ± **5 % uncertainty**

Combine DC & HiPIMS deposition techniques in a multi-layer structure!

DC	HiPIMS	DC	HiPIMS

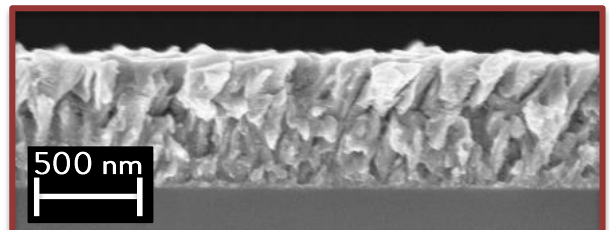
DC: **60 – 90 %** of the thickness
HiPIMS: **10 -40 %** of the thickness

✓ Stresses



✓ Density

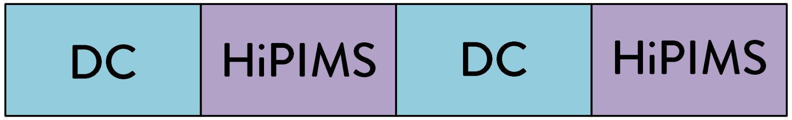
$\rho \approx 0.85\ \rho_{bulk}$



Success after sucrose removal!

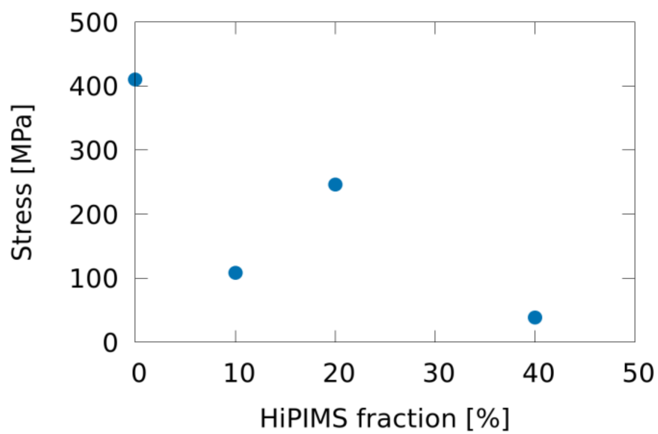
Substrate production between **600 - 1000 nm** thickness **± 5 % uncertainty**

Effect of the % of HiPIMS



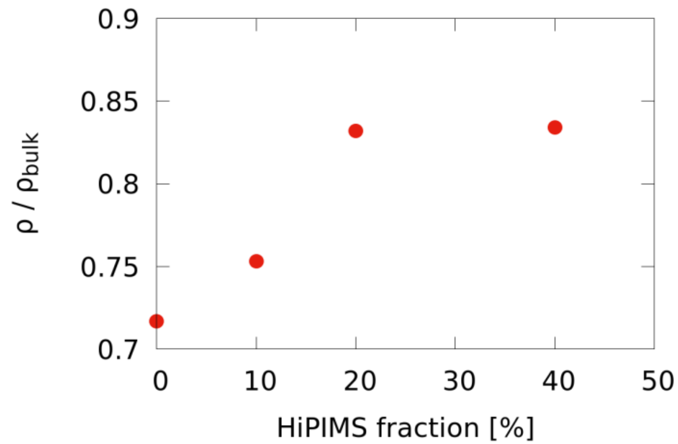
Total film thickness = 600 nm

- Stresses



↑ % HiPIMS → Reduce the stress state

- Density



↑ % HiPIMS → Densification

Increase of the HiPIMS fraction → beneficial effect on properties!

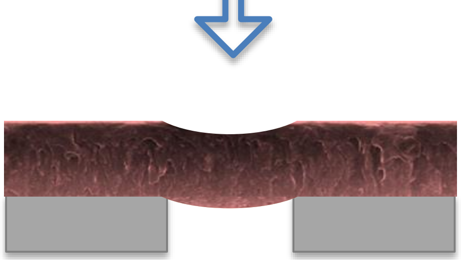
Outcomes

Reliable strategy to produce targets for laser-driven ion acceleration

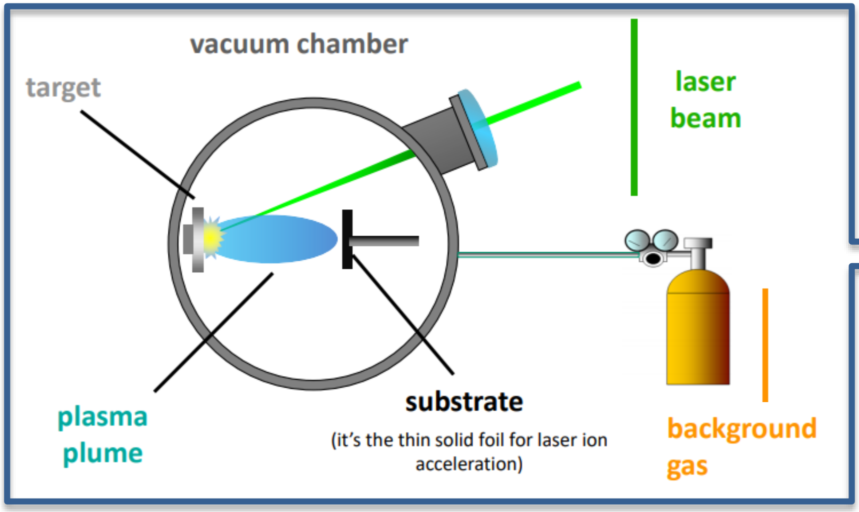
- Thicknesses ranging **from 300 nm up to 1 um**
- **Uncertainty** on the thickness lower than ± 5 %
- **Compact morphology** with high density values (up to 90 % of the bulk)

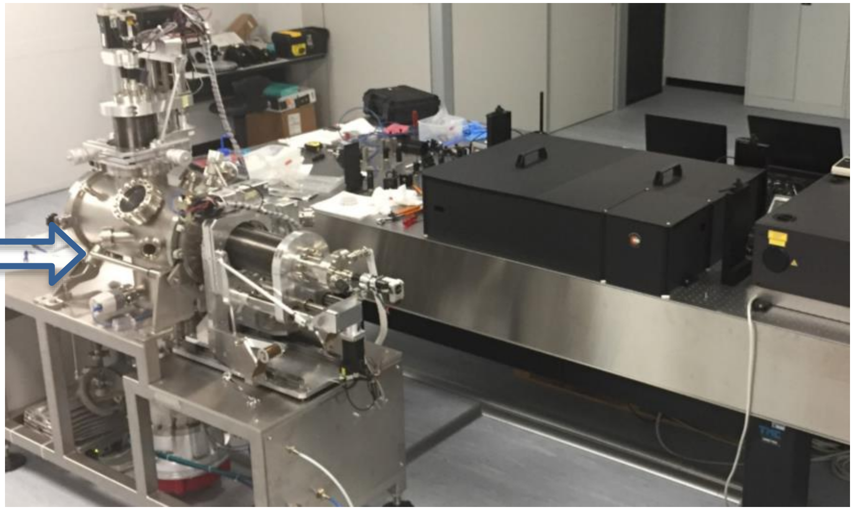
Possible improvements?

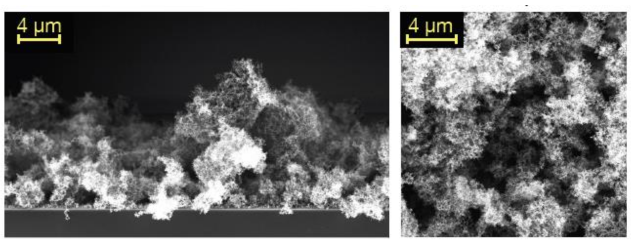
- Extend the thickness range (from **100 nm** to **several μm).**
- **Improve** the control of **structural integrity.**
- Exploit the co-deposition of **several materials.**



Next step…production of an integrated double layer target with ns & fs - PLD

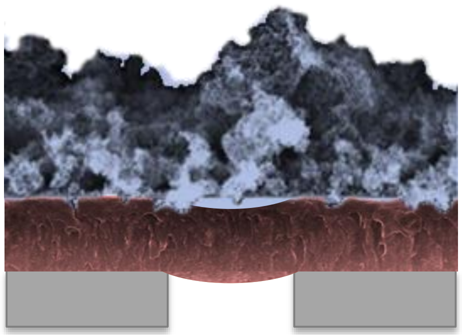






A. Maffini et al., "On the growth dynamics of pulsed laser deposited nanofoams" under review to Physical Review Materials.

See Andrea Pazzaglia presentation

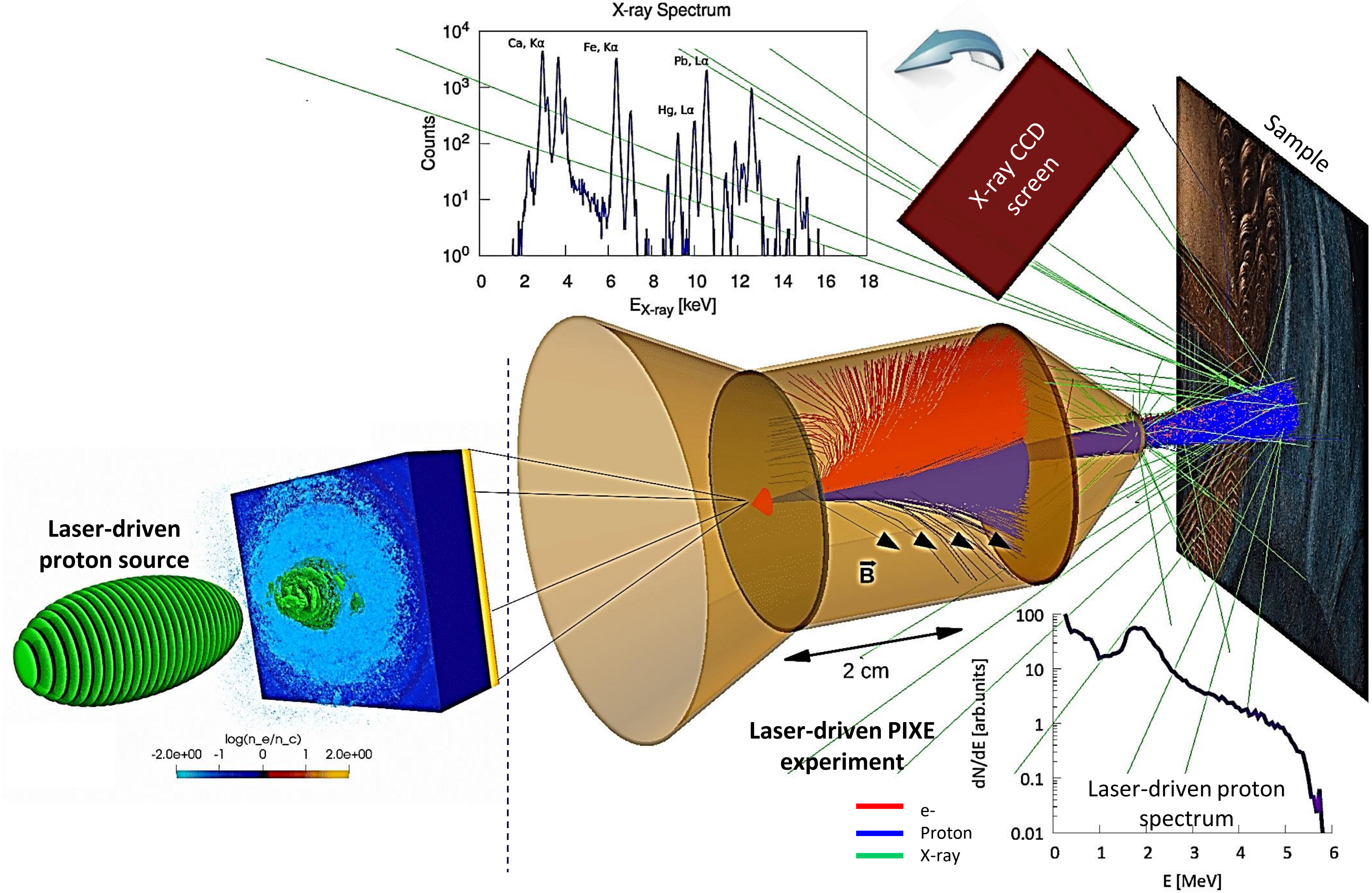


Zani, A., et al., Carbon 56 (2013): 358-365.

I. Prencipe et al., Plasma Phys. Control. Fus. 58 (2016)

Towards the applications

❖ Laser-driven Ion Beam Analysis



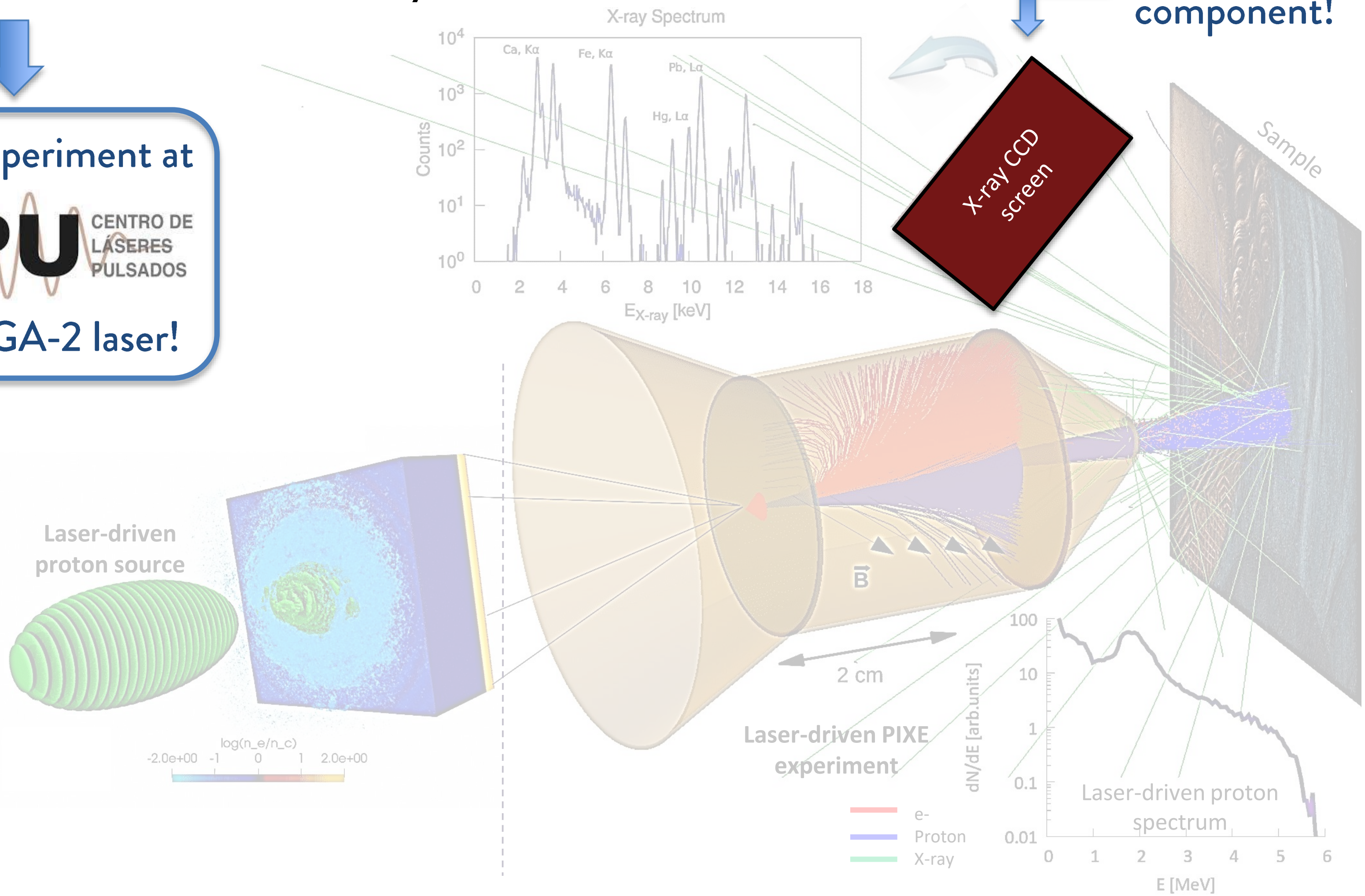
Passoni M., Fedeli L and Mirani F. Superintense Laser-driven Ion Beam Analysis (2019). Scientific Reports

Towards the applications

- Laser-driven Ion Beam Analysis

Recent experiment at CLPU (Centro de Láseres Pulsados) with VEGA-2 laser!

Critical component!

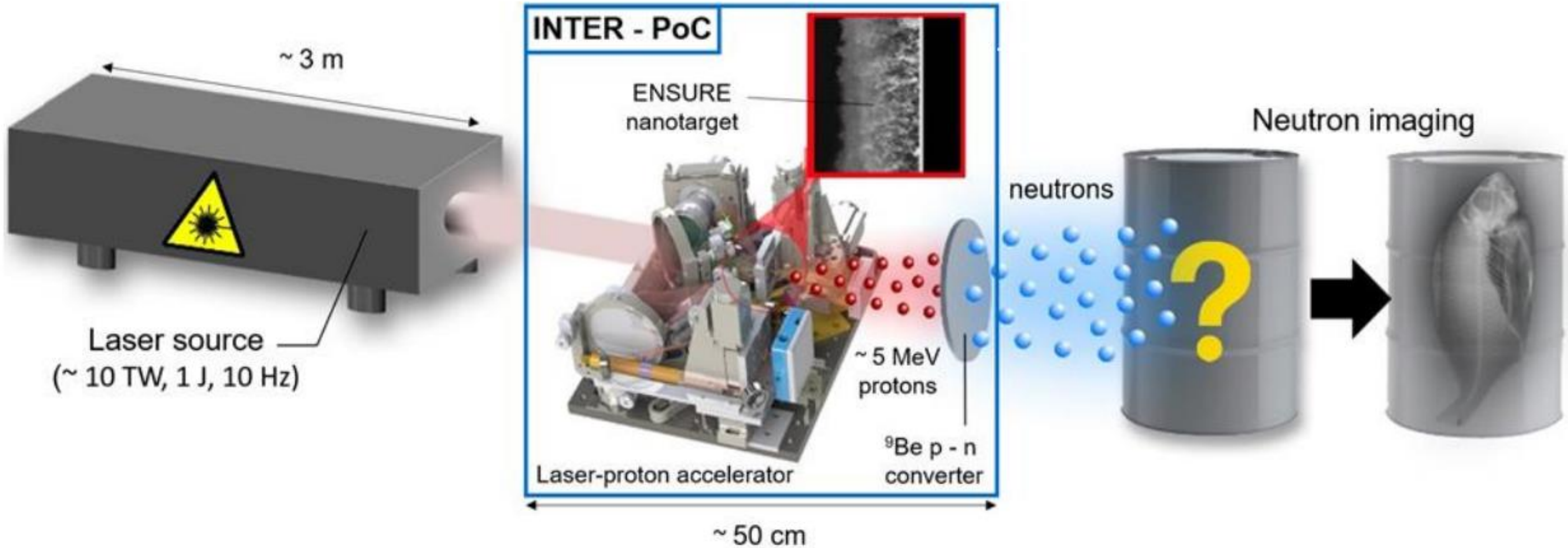


Passoni M., Fedeli L and Mirani F. Superintense Laser-driven Ion Beam Analysis (2019). Scientific Reports

Towards the applications

❖ Laser-driven neutron sources

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



❖ Radioisotope production

A. C. Giovannelli Master's thesis, Politecnico di Milano, Italy (2019)

Acknowledgments

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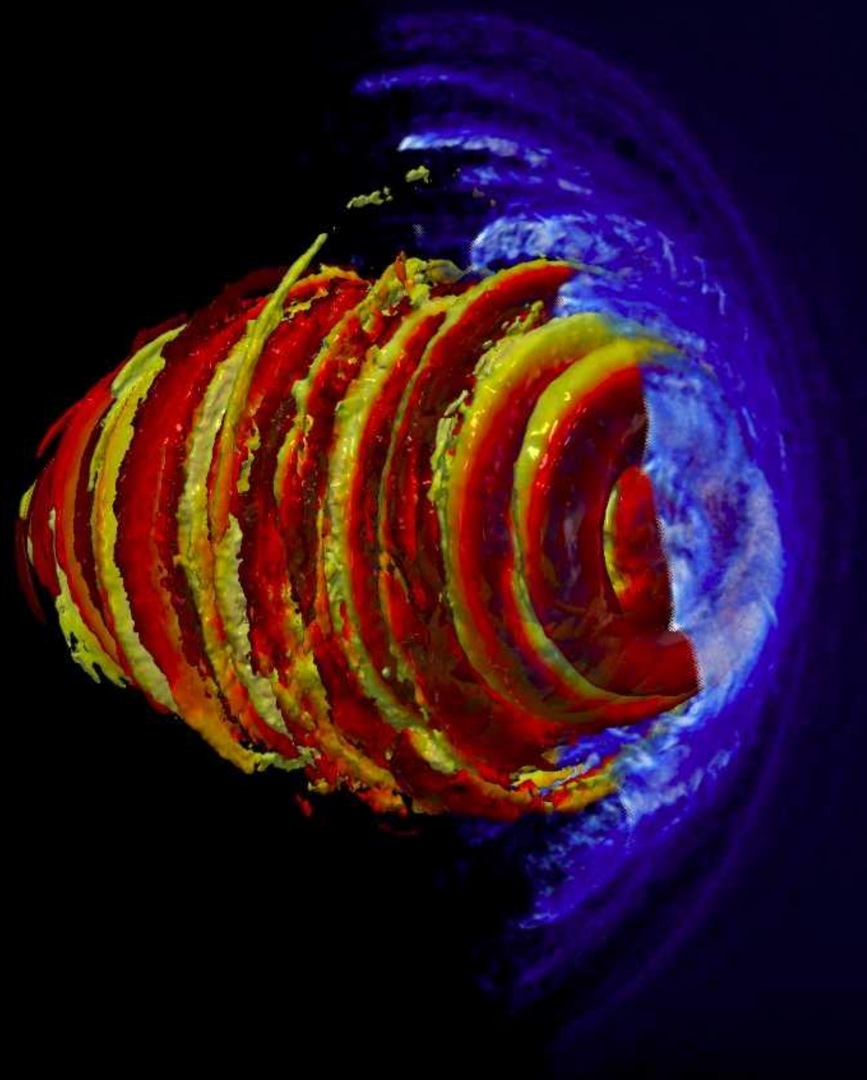
NanoLab
SourceLAB

46th PLASMA PHYSICS Conference EPS 2019 July 8-12, Milan

High-Field Laser Plasma Interaction

https://www.hflpi.polimi.it/



Thank you for your attention!

Near-critical targets for laser-driven acceleration

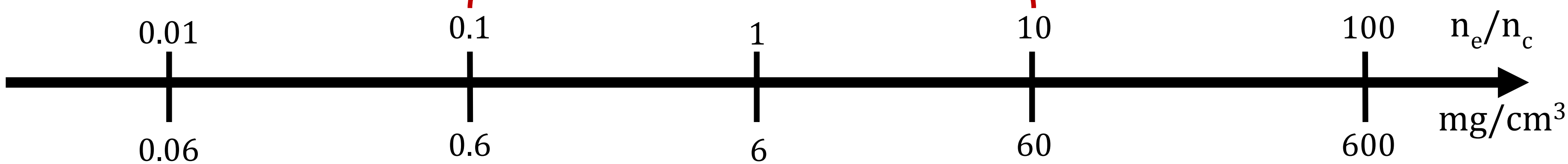
I_{laser}=10^{20} W/cm^2 ⟶ $\mathbf{E}_{laser}$ = 3 x 10^{11} V/m = 50 X $\mathbf{E}_{atomic}$ ⟶ Full ionization ⟶ Plasma!

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)

$n \approx n_c$ near critical plasma
strong laser-plasma coupling

$n \ll n_c$ underdense plasma
little laser absorption

$n \gg n_c$ overdense plasma
most of laser is reflected

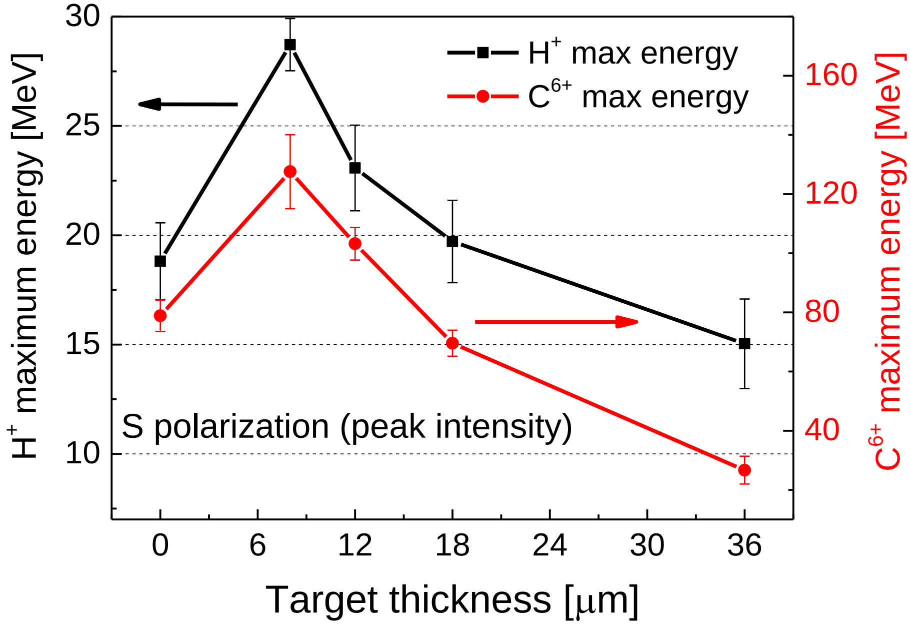


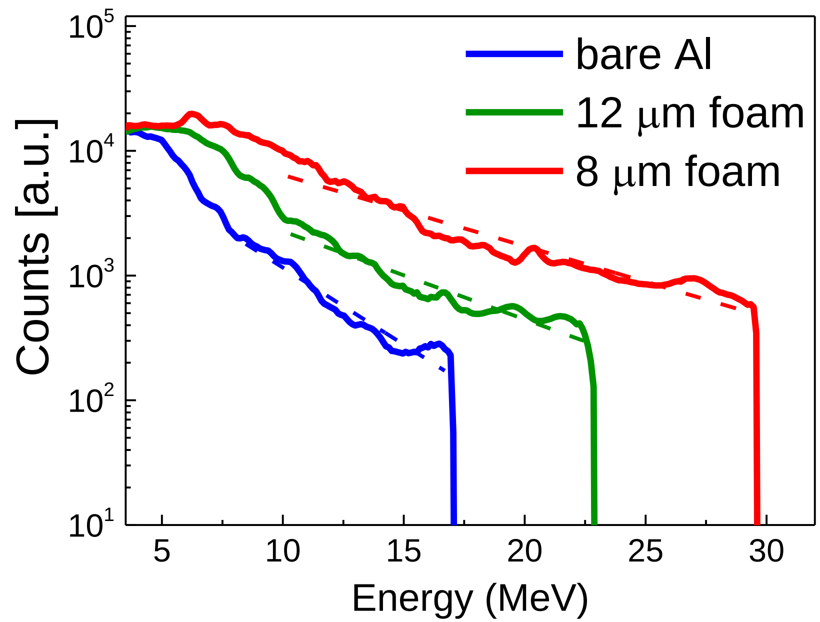
Ion acceleration @ PULSER (GIST)

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

Role of target properties (s-polarization, full power)

- **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**

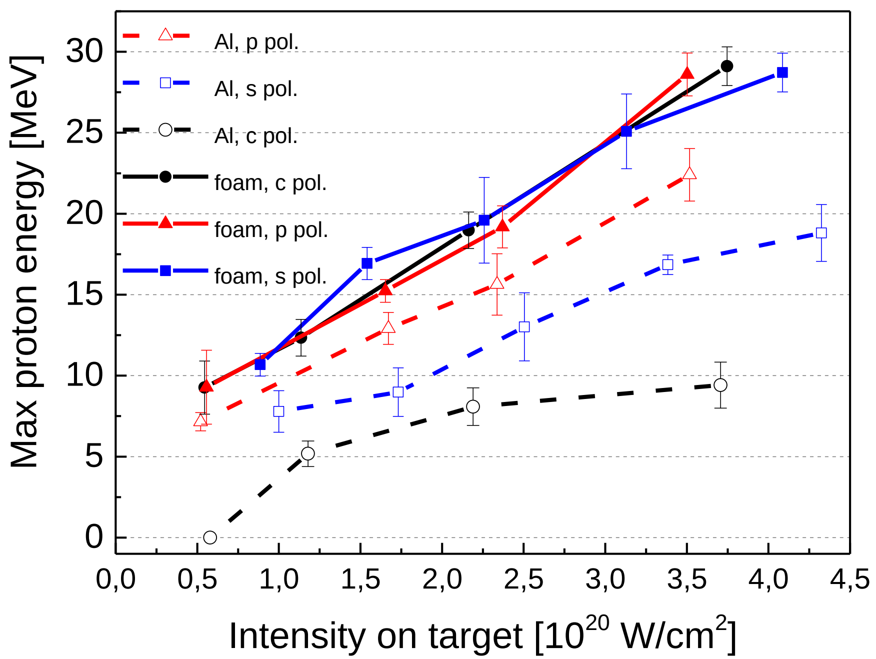
M. Passoni et al., *Phys. Rev. Accel. Beams* **19**, (2016)
I. Prencipe et al., *Plasma Phys. Control. Fus.* **58** (2016)

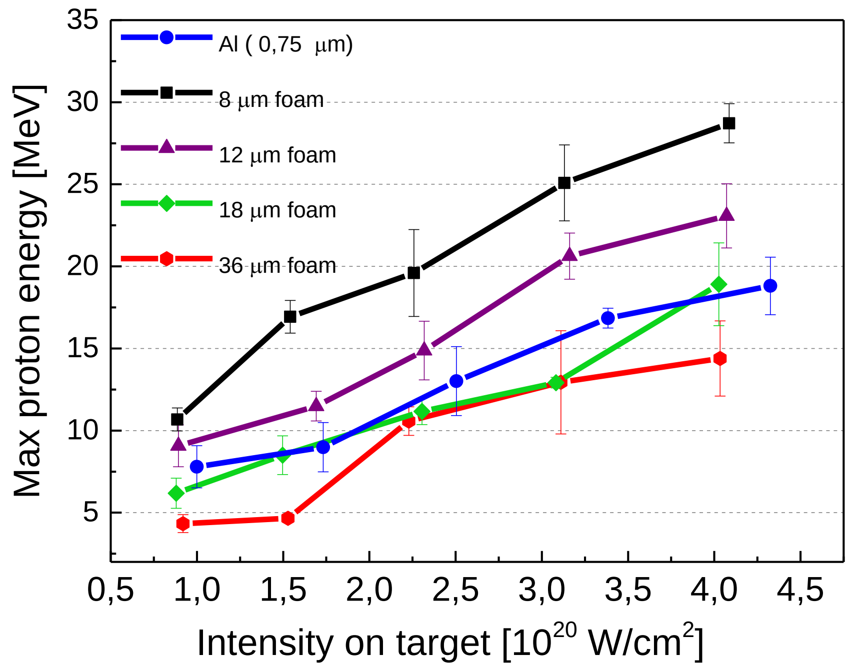
Ion acceleration @ PULSER (GIST)

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

Role of pulse properties Al (0.75 µm) + foam (6.8 mg/cm³, 8 µm)

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





Dependence on **polarization**:

- strong for Al foils
- reduced for foam targets

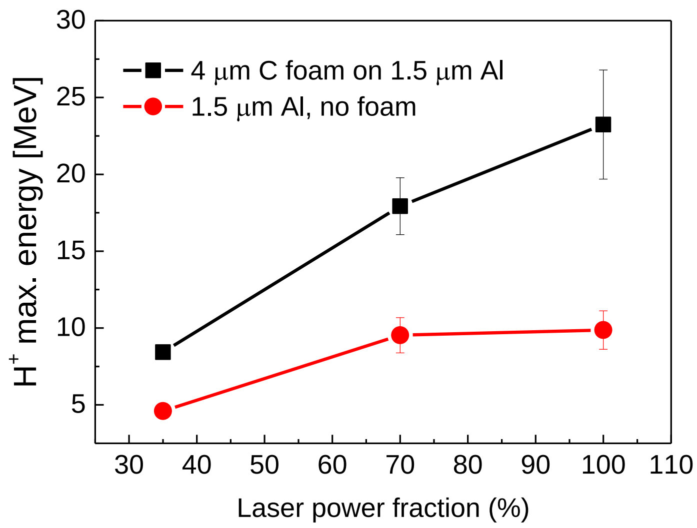
- foam vs Al: **volume vs** surface interaction?
- irregular foam surface: polarization **definition**?
- role of target **nanostructure**?

Ion acceleration @ DRACO 150 TW
(preliminary data!)

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

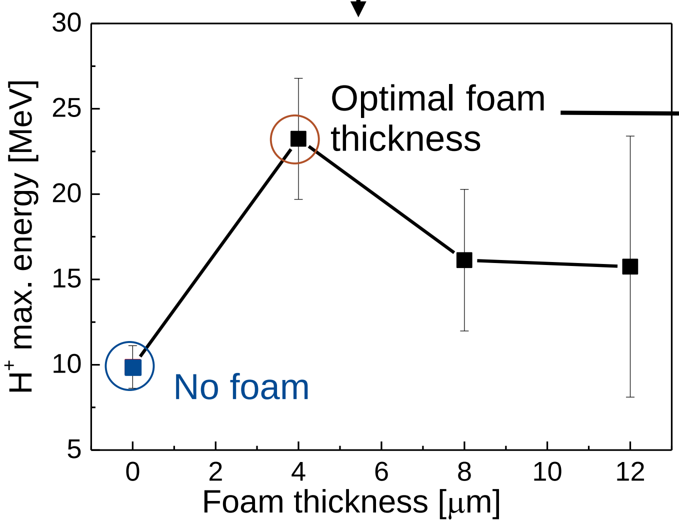
Laser parameters @ Draco (HZDR, Dresden)

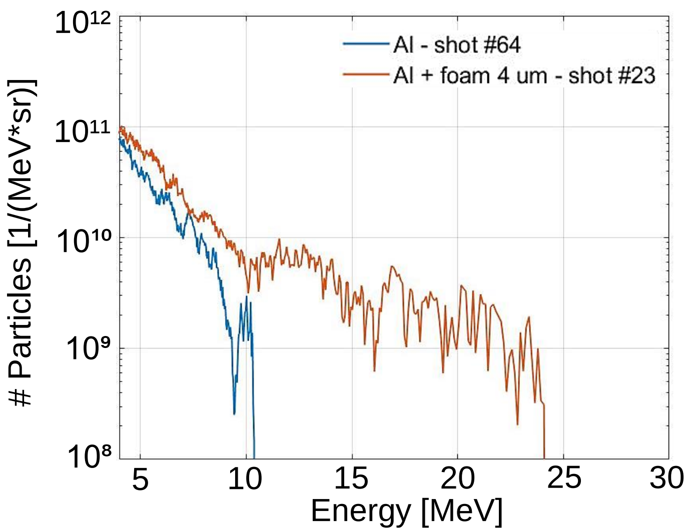
- Energy on target = 2 J
- Intensity = up to 5 x 10^{20} W/cm^2
- Angle of incidence = 2°



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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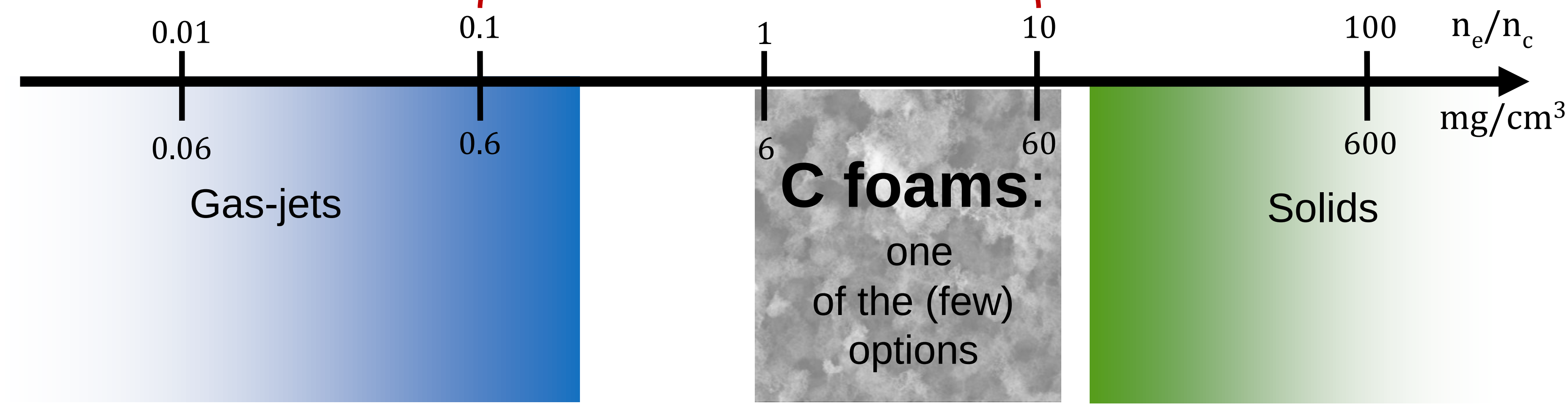
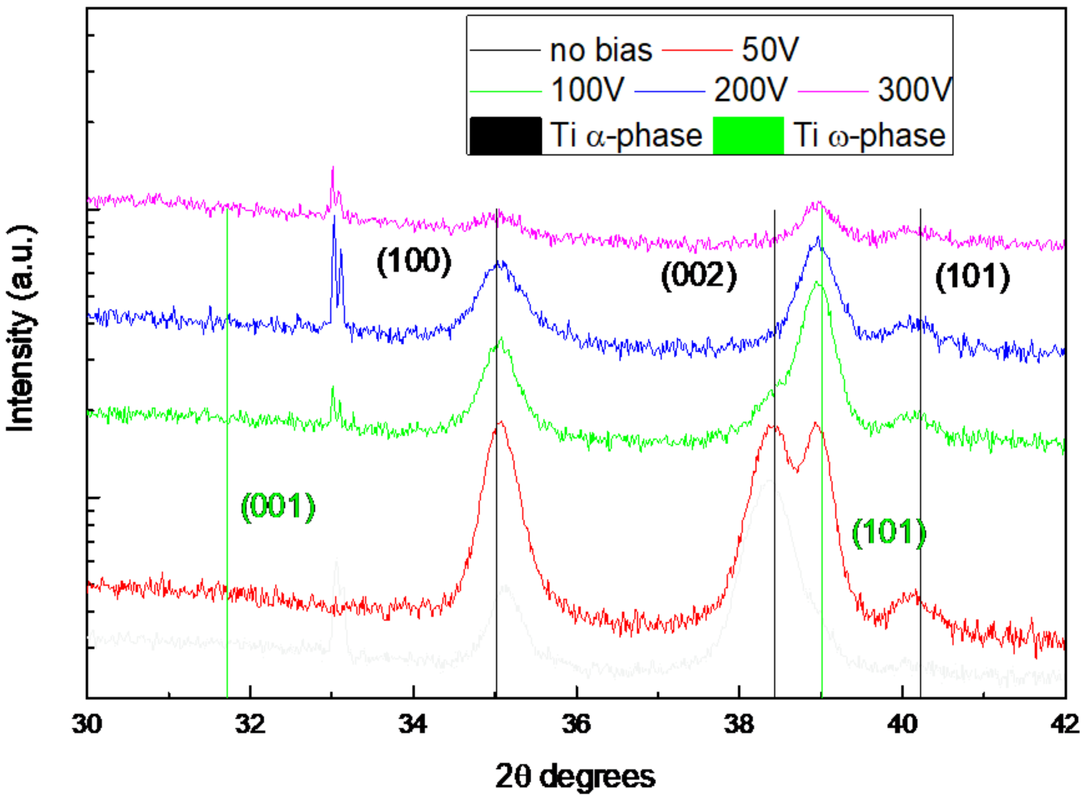


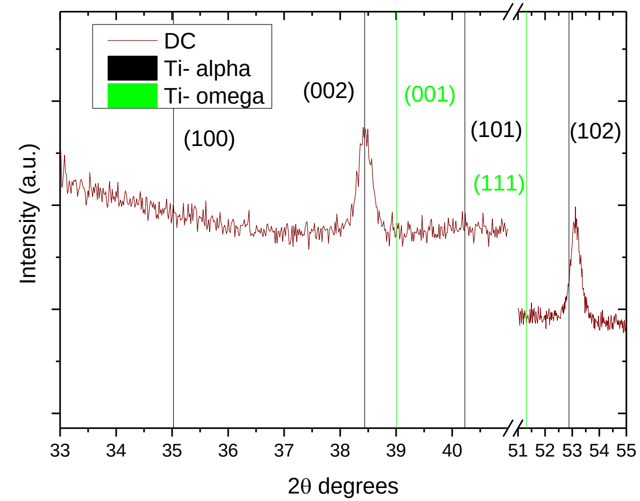
Presence of the bias: XRD analysis

❑ HiPIMS

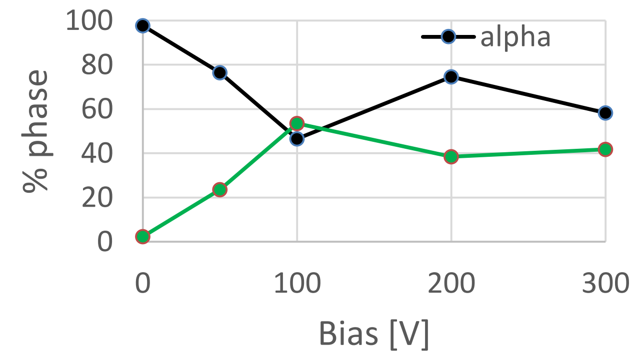
- Oriented groth;
- Transition: **fase α → fase ω?**



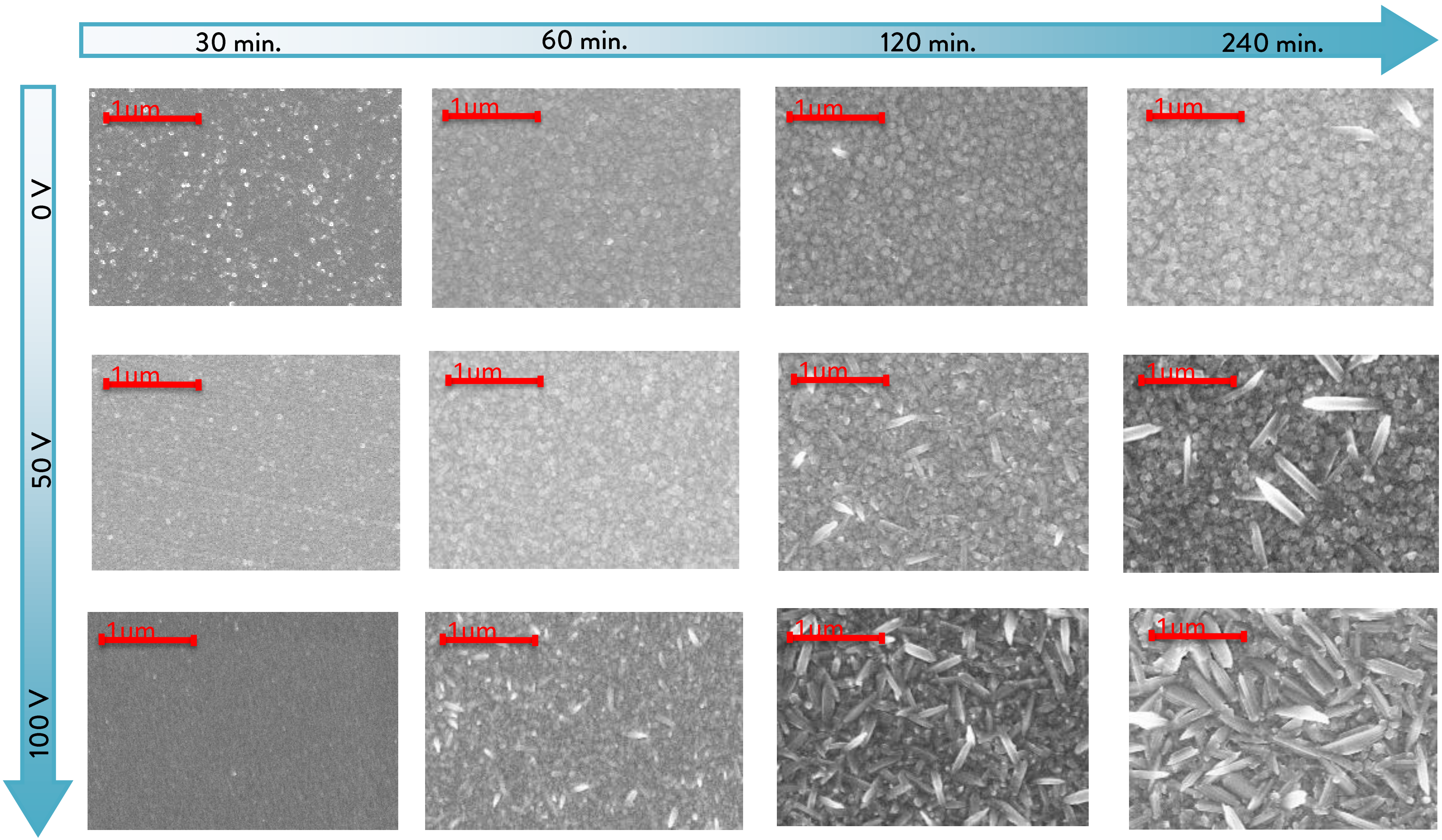
❑ DC **(only α phase)**



Maud:

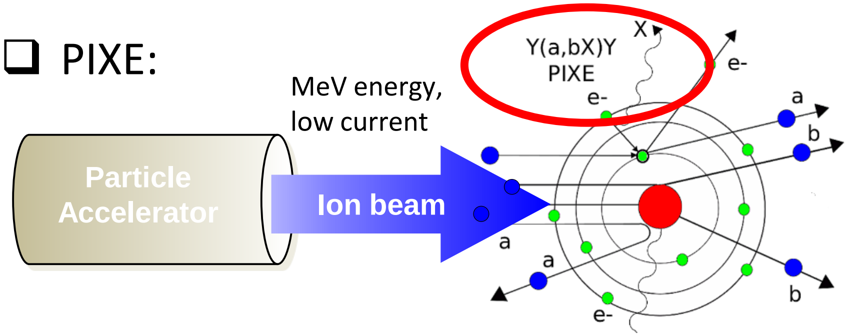


Morphology



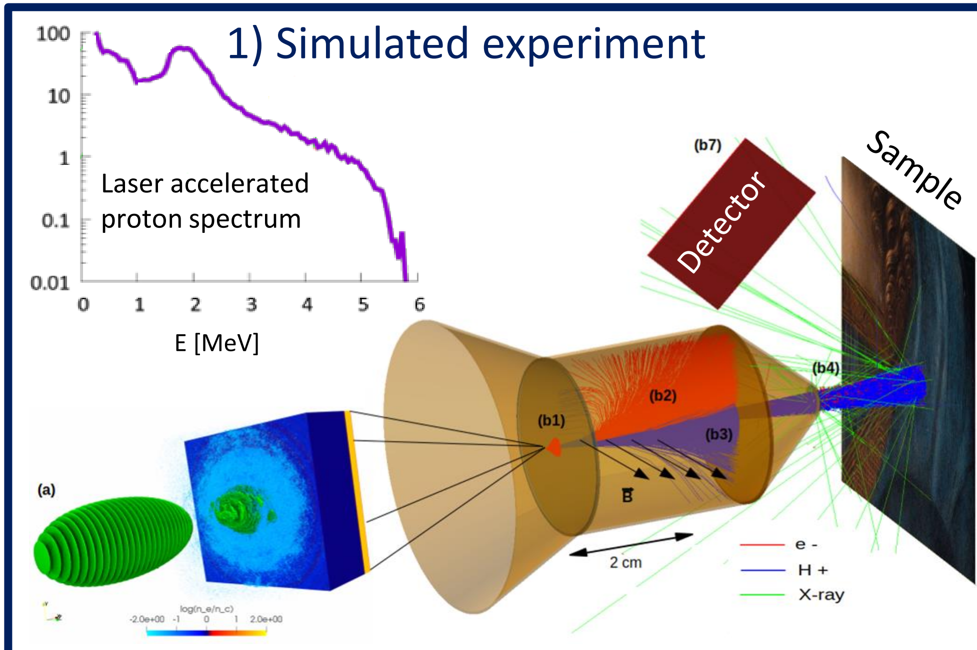
Laser-driven Particle Induced X-ray Emission (PIXE)

- ❑ PIXE:

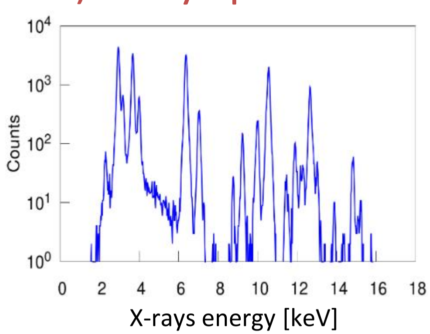


- ❑ Laser-driven PIXE:
  - ✓ **Unconventional features** of ion beam (broad spectrum, tunable energy, ns bunch duration)
  - ✓ **Cheaper, portable** PIXE setup
- ❑ Commercial codes not ok for laser PIXE
  - ✓ Ad-hoc code developed

1) Simulated experiment



2) X-ray spectra



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

3) Sample composition