IAEA-CN301-77

# Toward Laser-Driven accelerators: exploring the potential of advanced Double-Layer Targets


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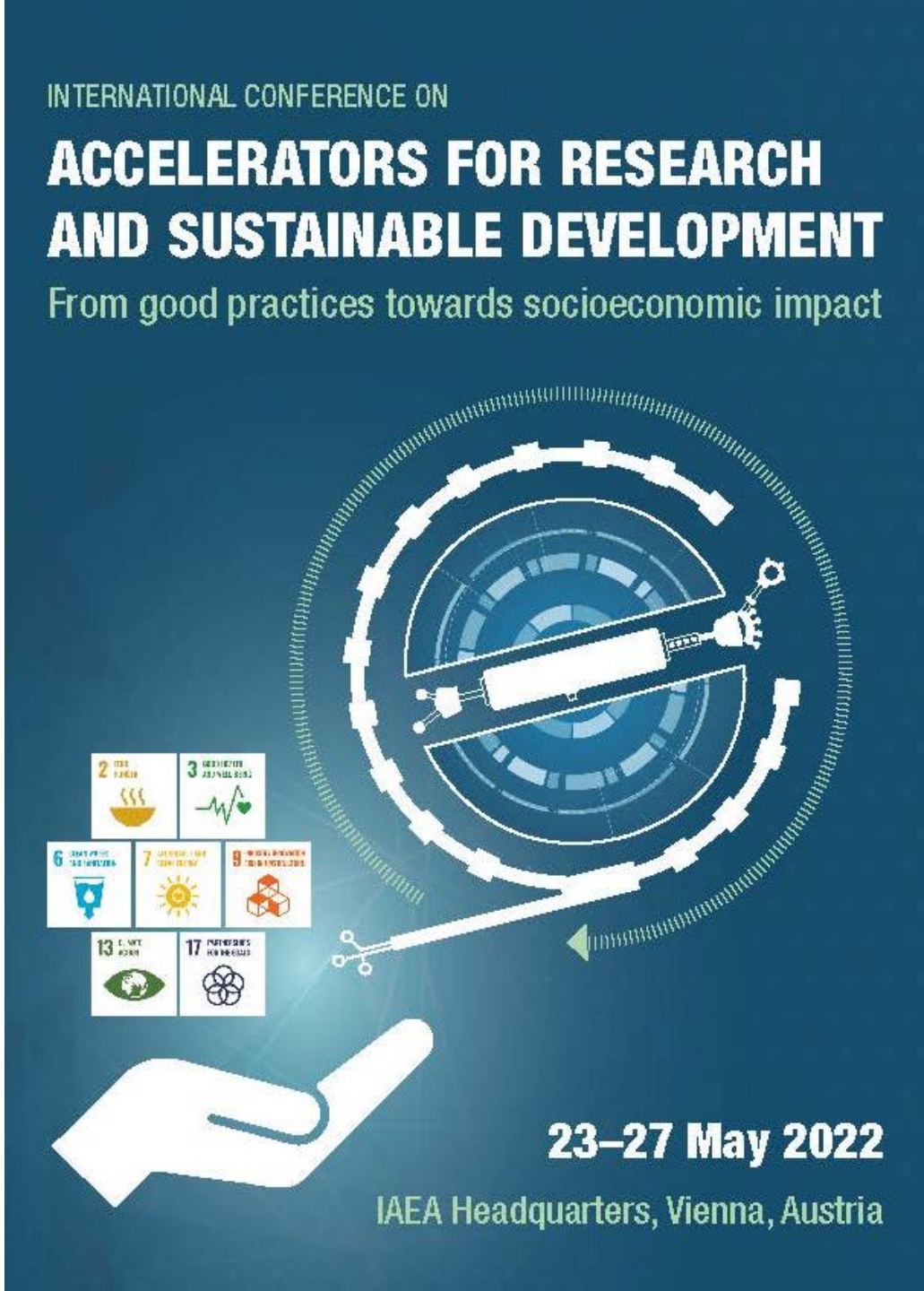

# Outline:

- What is Laser-Driven Acceleration (and why) ?
- Case study 0: Laser-Driven Proton Induced X-ray Analysis
- Why Double-Layer Targets (DLTs)?
- Case study 1: Photon Activation Analysis with DLTs
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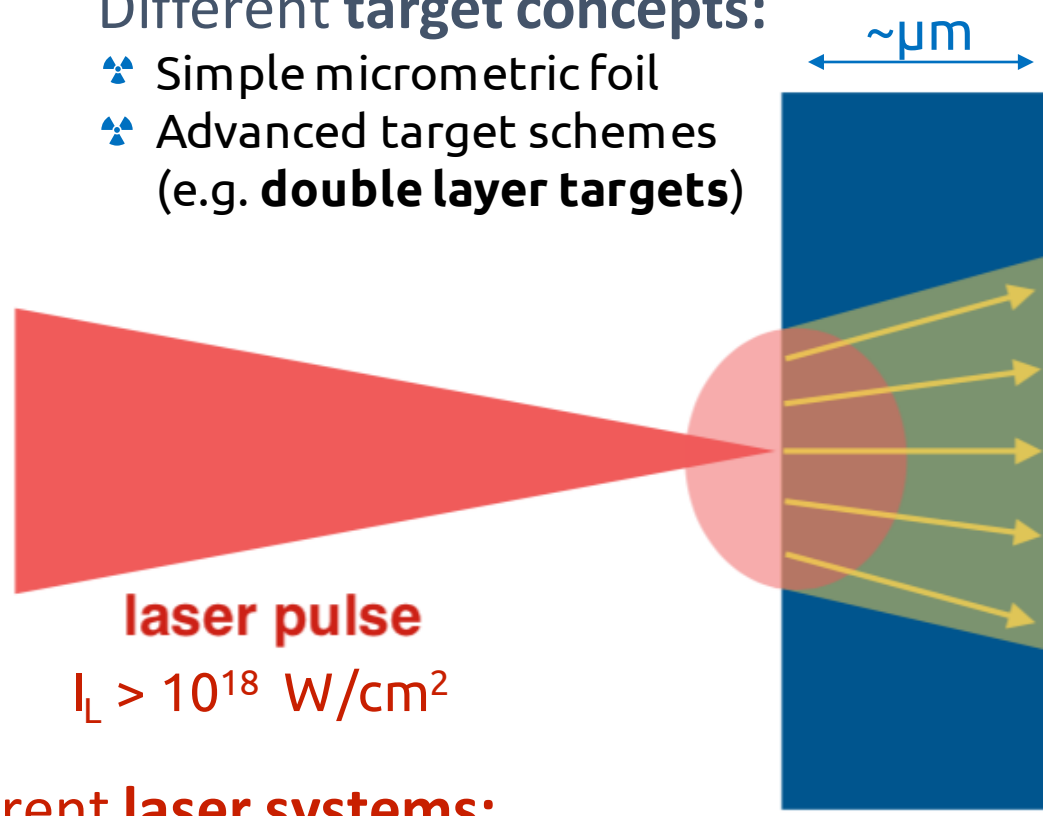
# Laser-driven particle acceleration

Different **target concepts:**

- Simple micrometric foil
- Advanced target schemes (e.g. **double layer targets**)




Different **laser systems:**

- 0.1-1 J (30 fs), **10s TW**, 1-10 Hz, **Table-top**
- 1-20 J (30 fs), **0.1-1 PW**, < 1 Hz, **Room size**
- 50 J-1 kJ (~ ps), **0.1-1 PW**, 10s/day, **Building size**

M. Passoni et al., PPCF 61, 014022 (2020)

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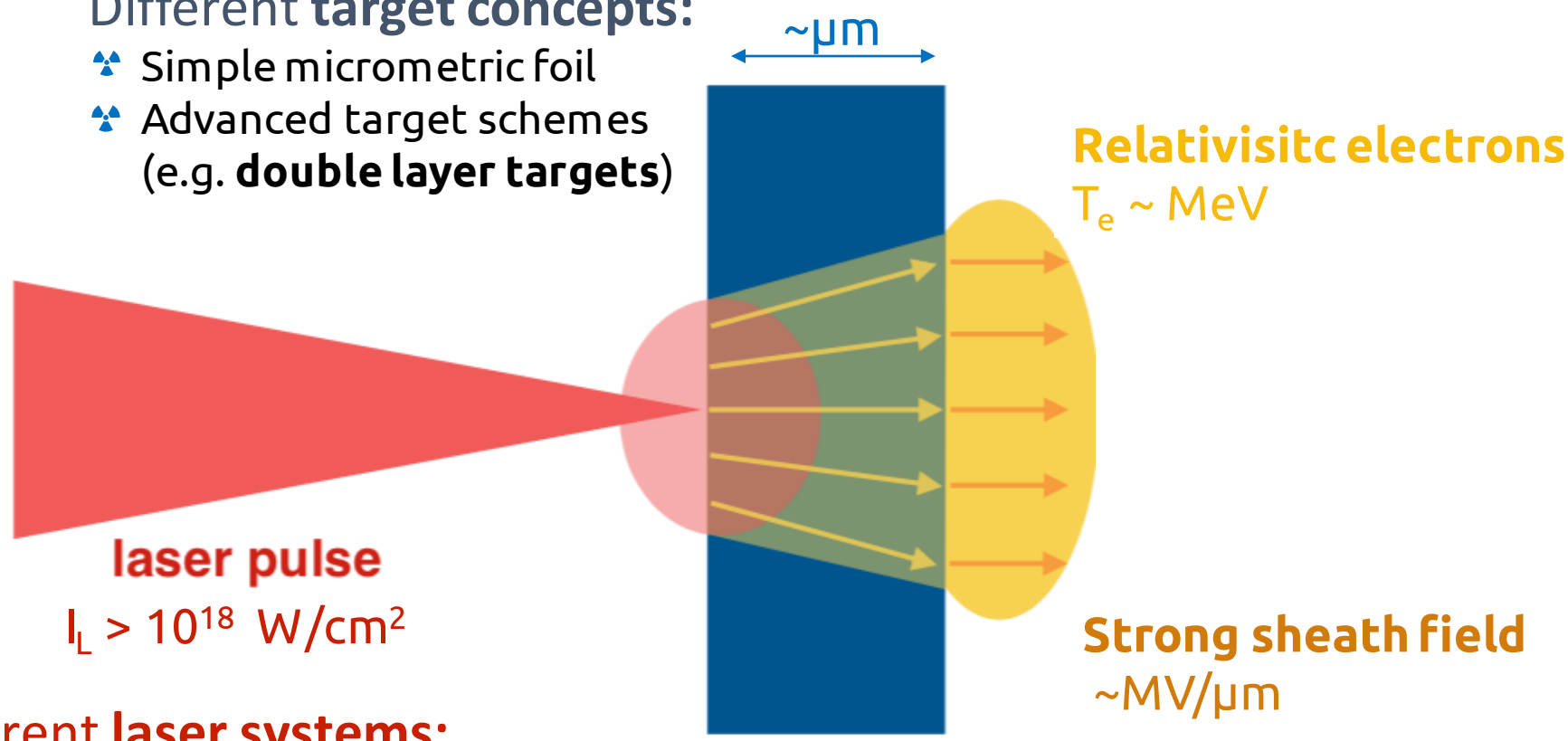


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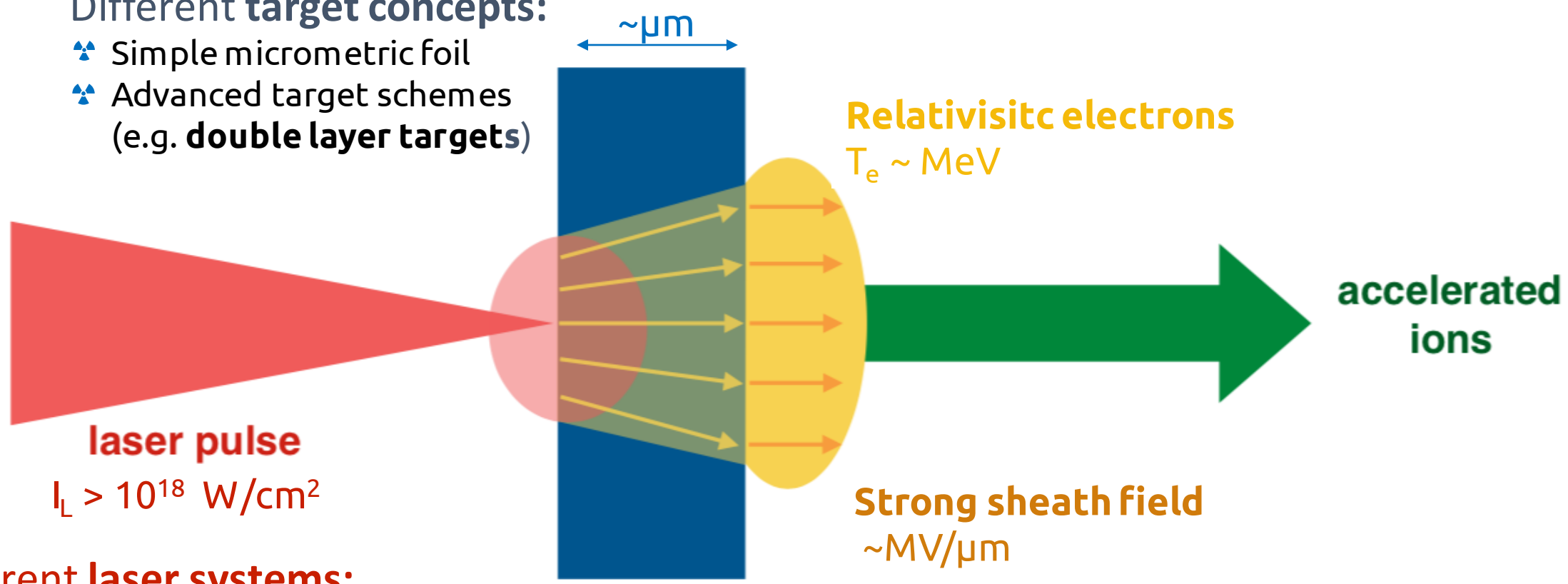


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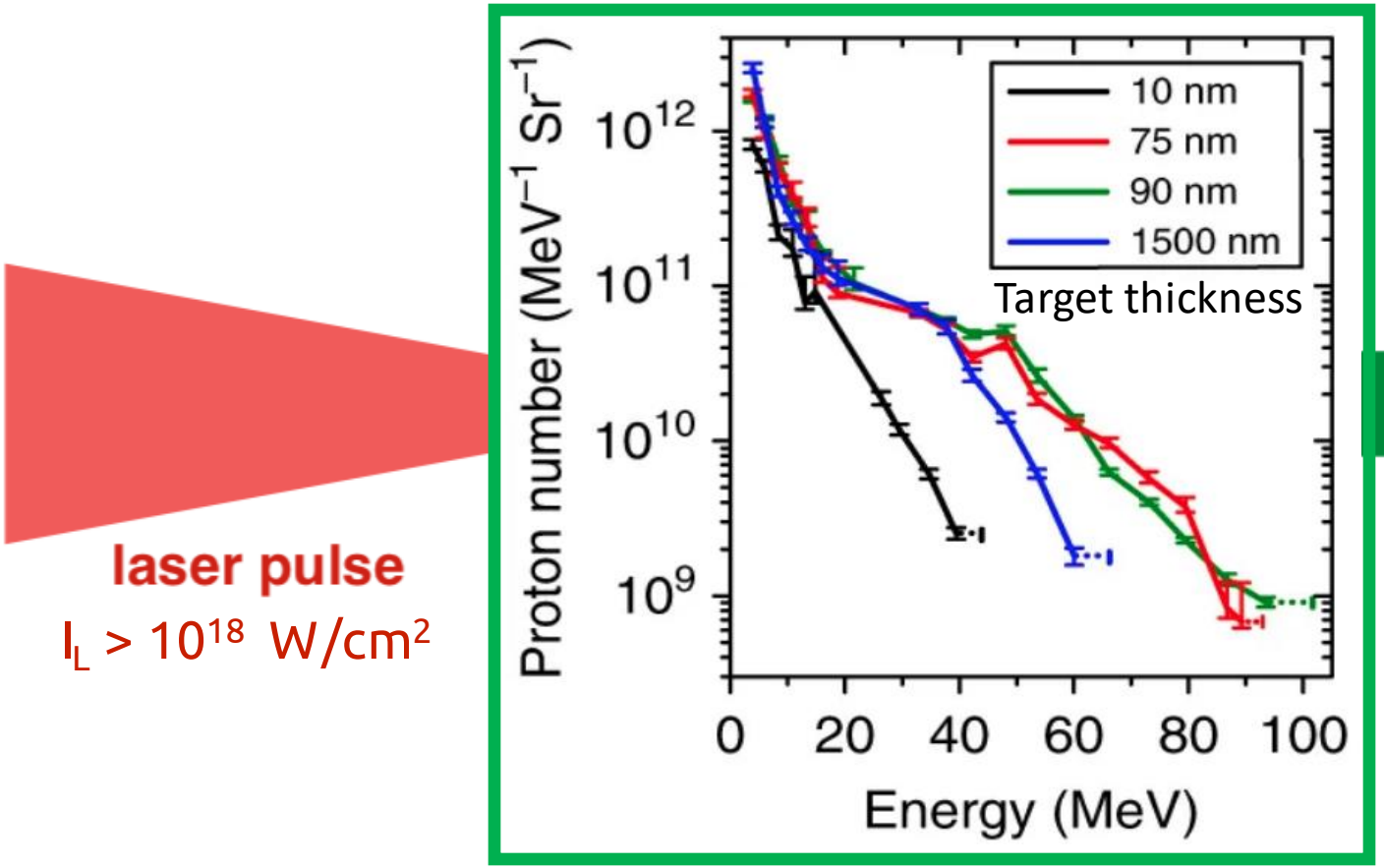


**laser pulse**

$I_L > 10^{18}$ W/cm$^2$

**Exponential-like**
Proton Spectrum

**accelerated ions**

Time width ~ few ps
$T_p$ ~ a few MeV
$E_{max}$ ~ 10s of MeV

A. Higginson et al., Nature Comm. 9, 724 (2018)

# Why should we try with lasers?

## Potential advantegs of laser-driven accelerators

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- **Ultra-short**: access to ultra-fast (~10 ps - ns) dynamics
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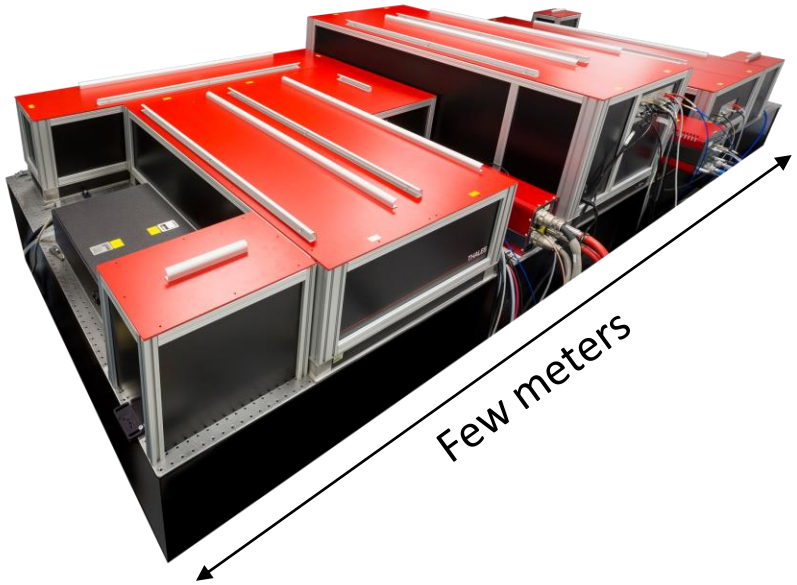


Commercial example of a laser system:
QUARK 45 TW, Thales Group

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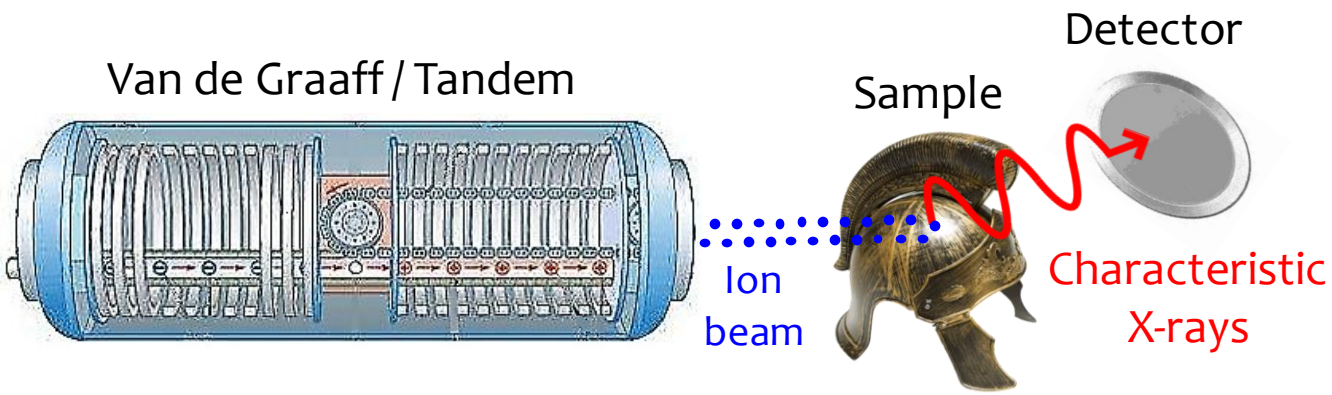
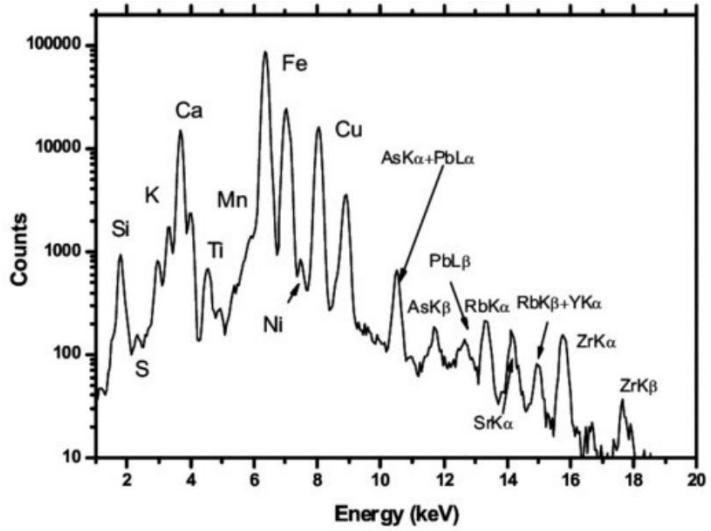
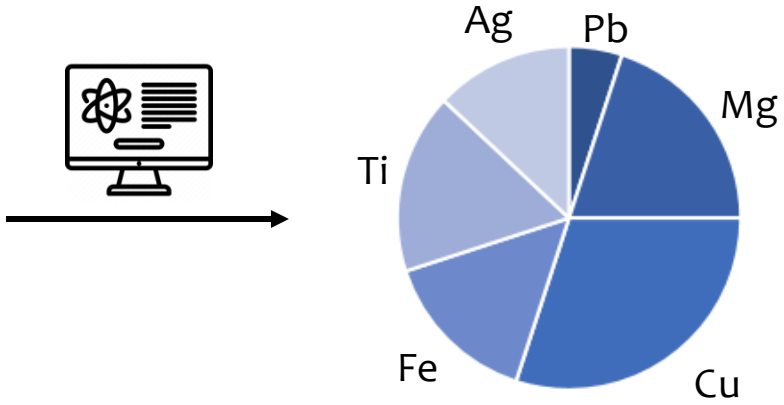
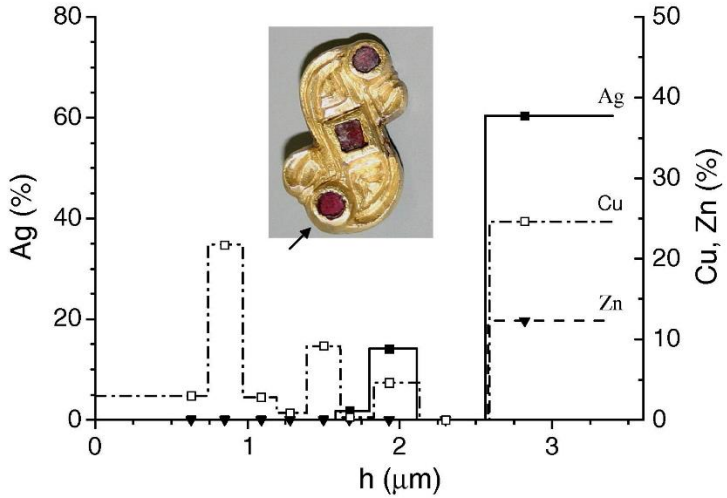
# Conventional PIXE




- **2-5 MeV/u** monoenergetic ions
- **Concentrations** & **Depth profiles**
- Cultural heritage, environment, biology, forensic analysis



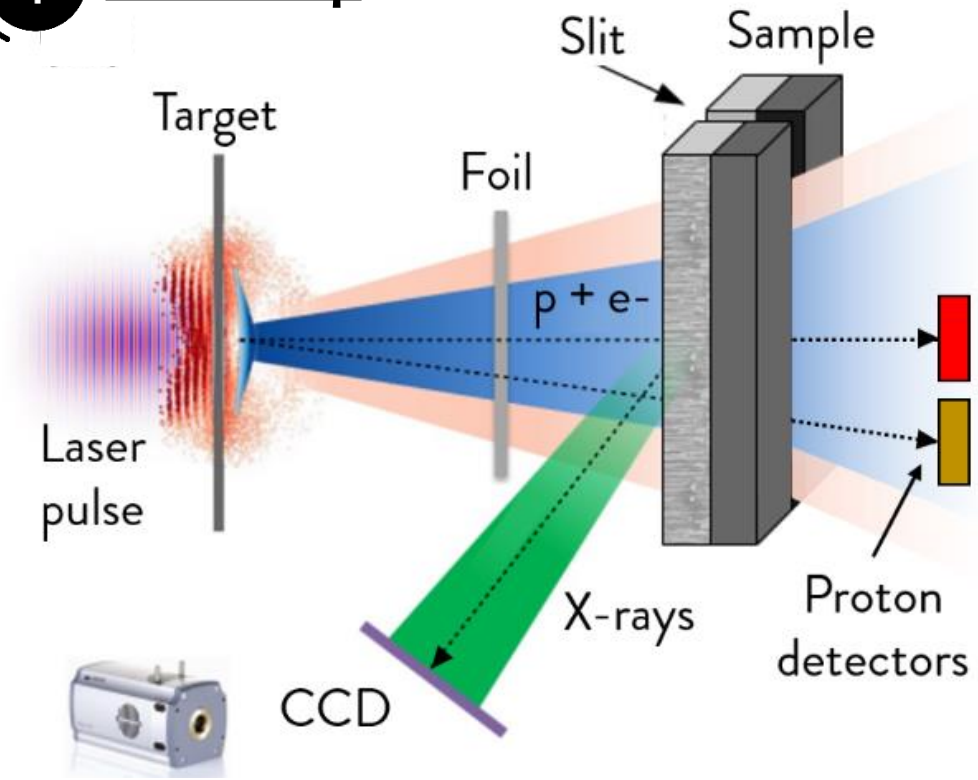




Verma, Hem Raj. Atomic and nuclear analytical methods. Springer-Verlag Berlin Heidelberg, 2007.

Žiga Šmit, et al. Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms, 266(10):2329–2333, 2008.

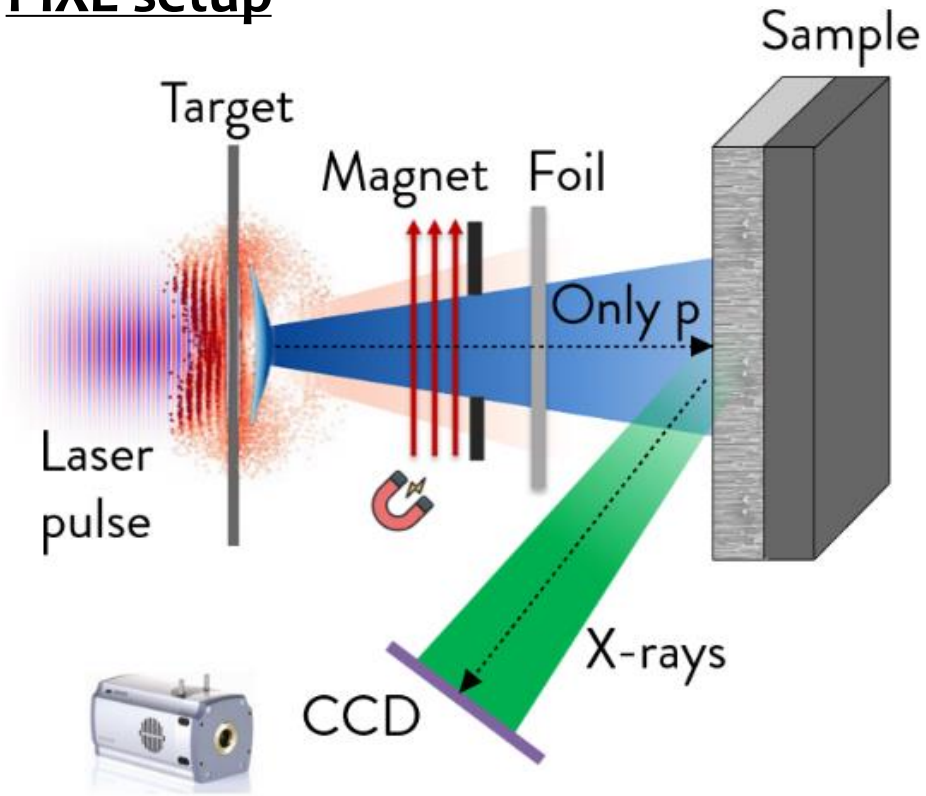
# Laser-driven EDX and PIXE

## 1 EDX setup




- Sample **irradiation** with **both electrons** and **protons**

## 2 PIXE setup



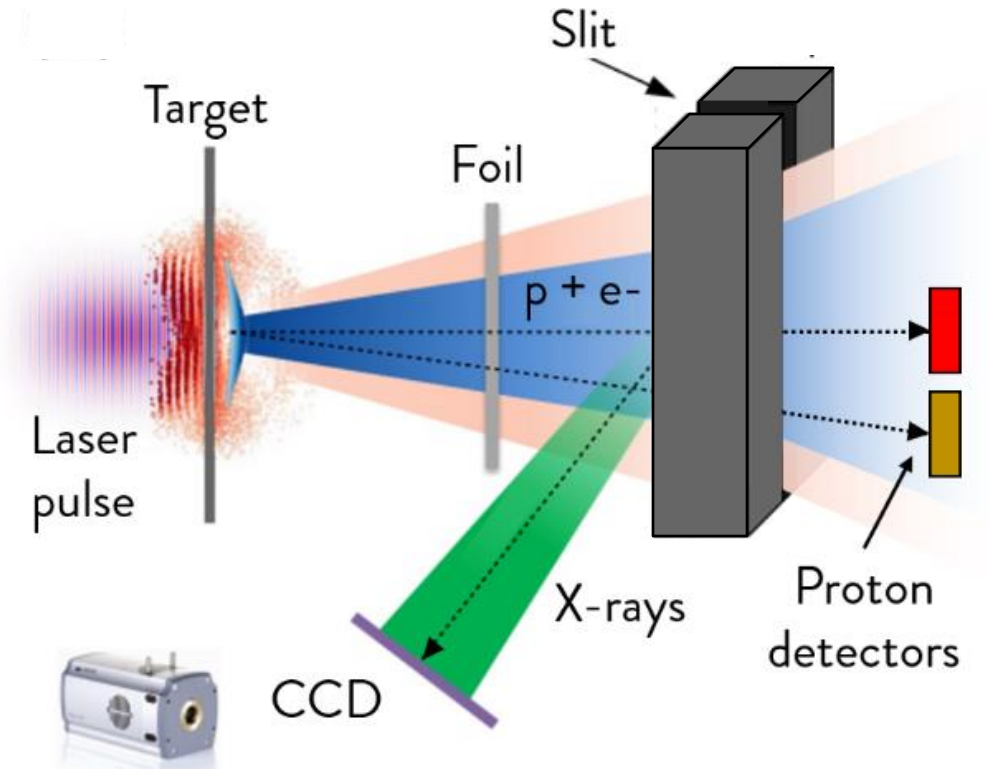

- Magnet to **remove** the **electrons**

Mirani, F., et al., Science Advances 7.3 (2021): eabc8660.

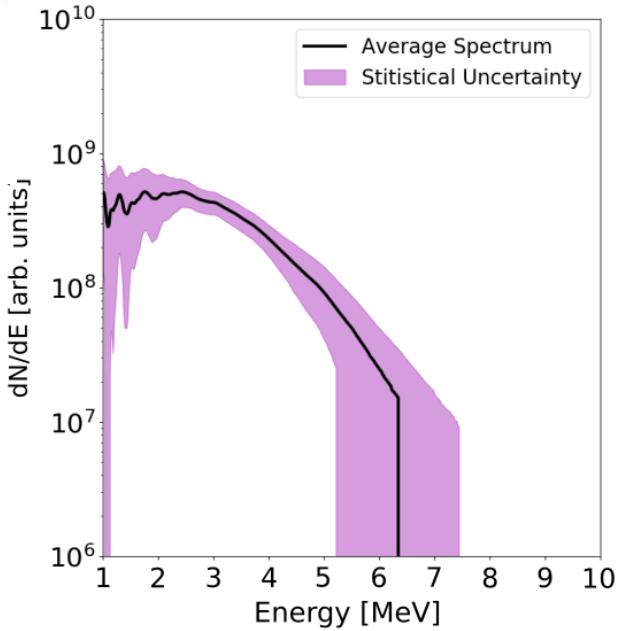
CLPU

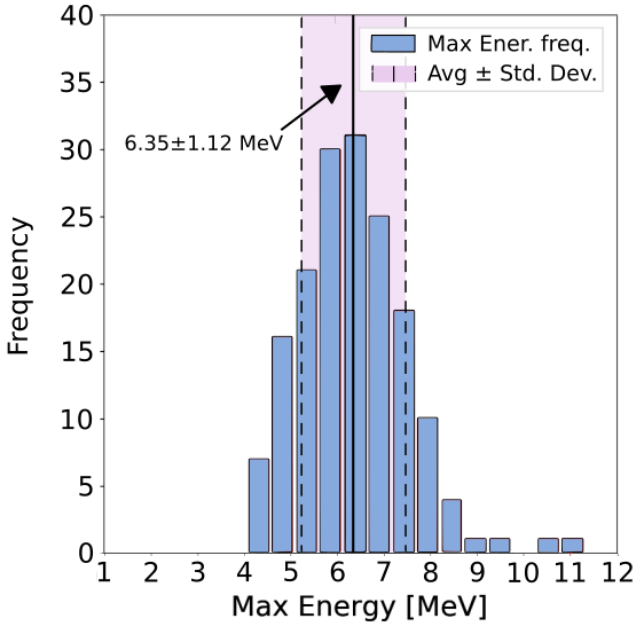
# Laser-driven EDX and PIXE

## 1 EDX setup → Sample **irradiation** with **both electrons** and **protons**




- **Aperture slit** in the middle of the sample
- **Proton** spectrum **characterization** (ToF)

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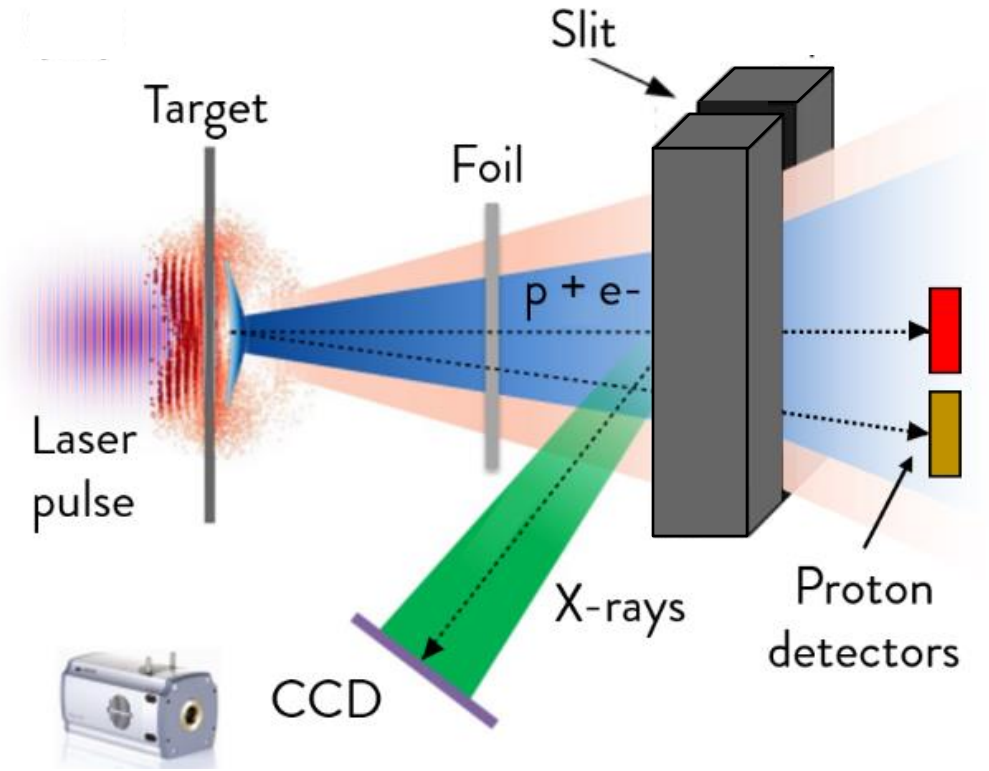
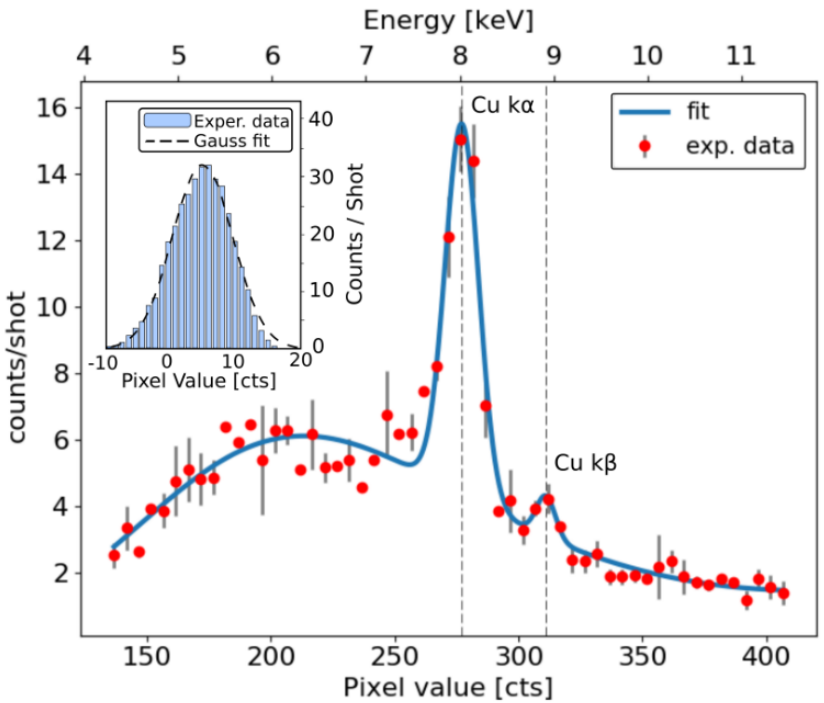



❖ X-ray **CCD** energy **calibration** (pure Cu sample)

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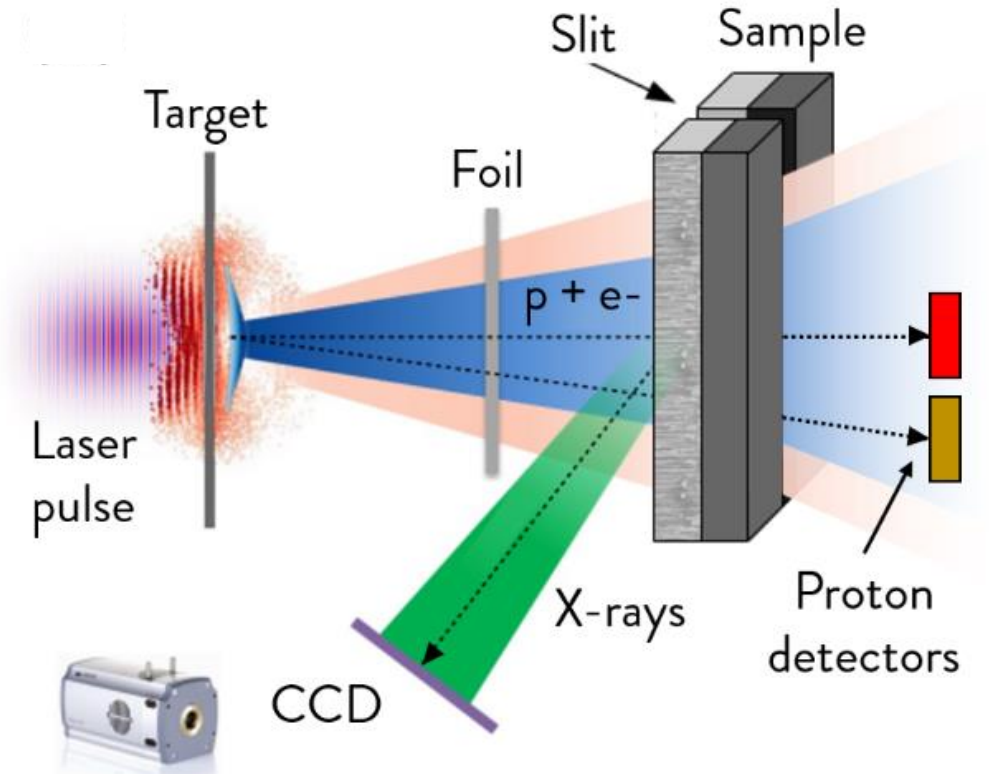
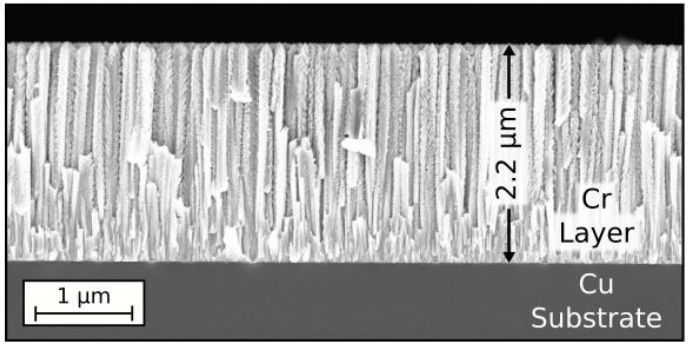
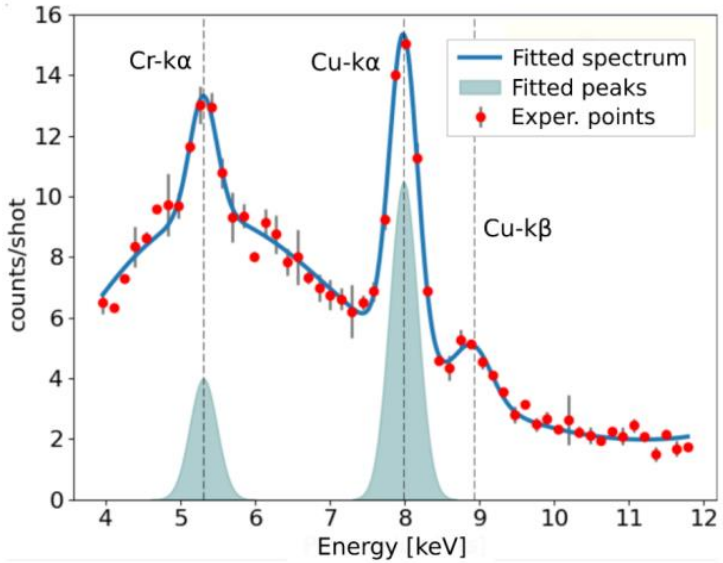
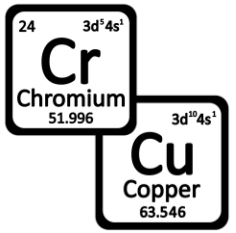



**Bi-layer sample** (Cr layer + Cu substrate)




→

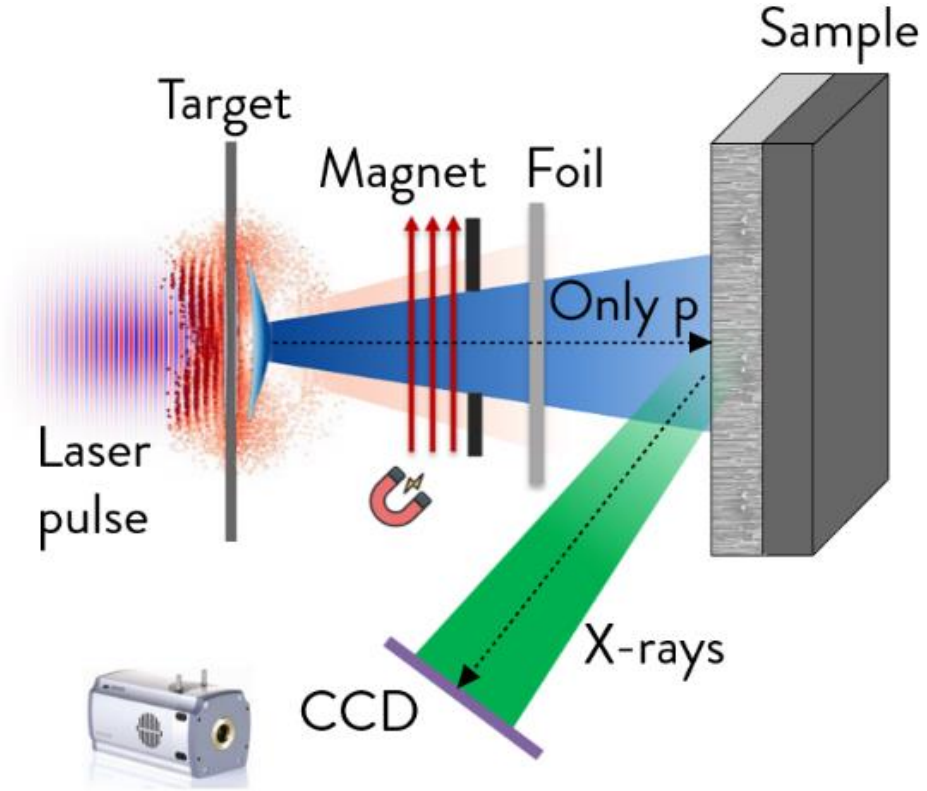



**Elements** are correctly **recognized**

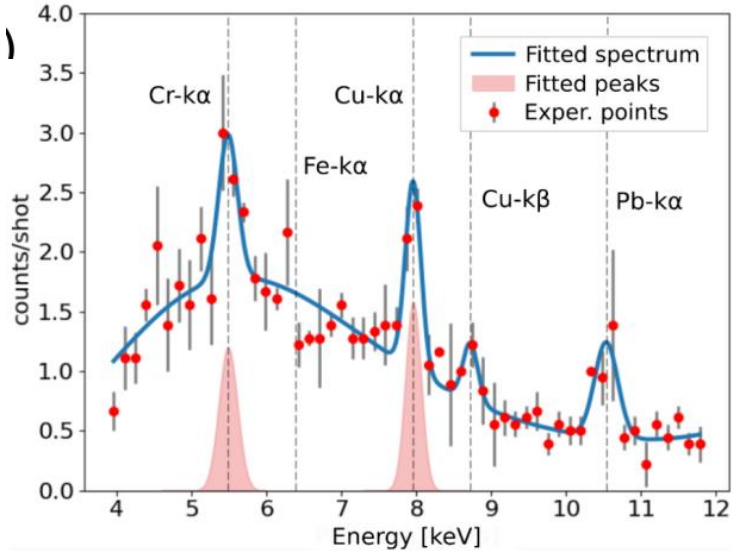
Mirani, F., et al., Science Advances 7.3 (2021): eabc8660.

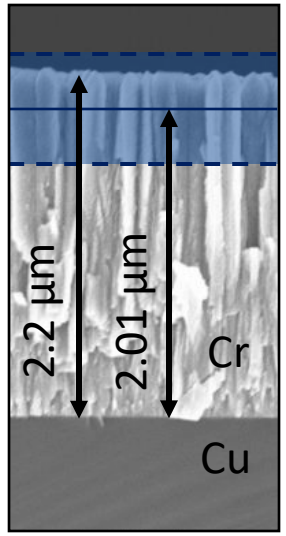
# Laser-driven EDX and PIXE

**2 PIXE setup** → **Removal** of the **electrons** with dipole magnet (0.26 T) and lead shielding




❖ **Sample thickness reconstruction** exploiting the model developed for the laser-driven PIXE analysis

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# Should we try with lasers?

## Potential advantages
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- **Compactness**: portability & cost reduction
- **Flexibility**: changing the laser/target parameters, you change the neutrons/ions properties
- **Ultra-short, pulsed**: access to ultra-fast (~10 ps - ns) dynamics & pump and probe
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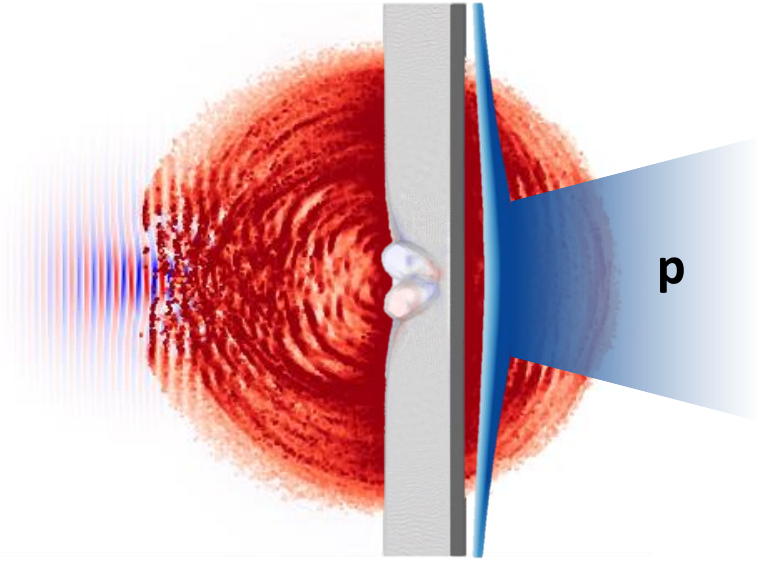
**Possible solution:** Double-Layer Targets



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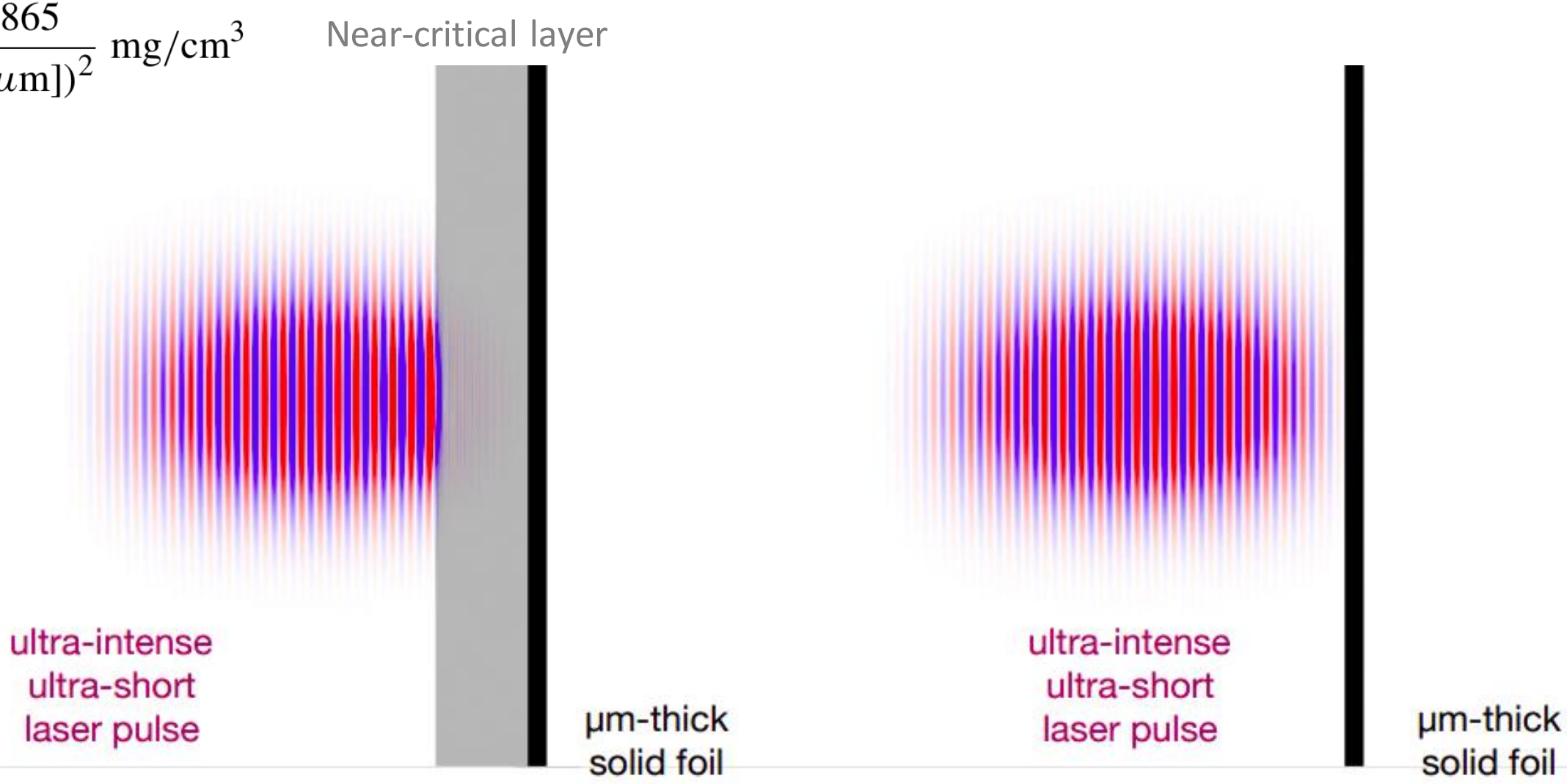
# Why Double-Layer Targets?

Near-critical layer density:

A. Pazzaglia, et al., Communications Physics 3, 133 (2020)

$$\rho_c \approx \frac{A}{Z}\frac{1.865}{(\lambda\,[\mu\mathrm{m}])^2}\ \mathrm{mg/cm^3}$$



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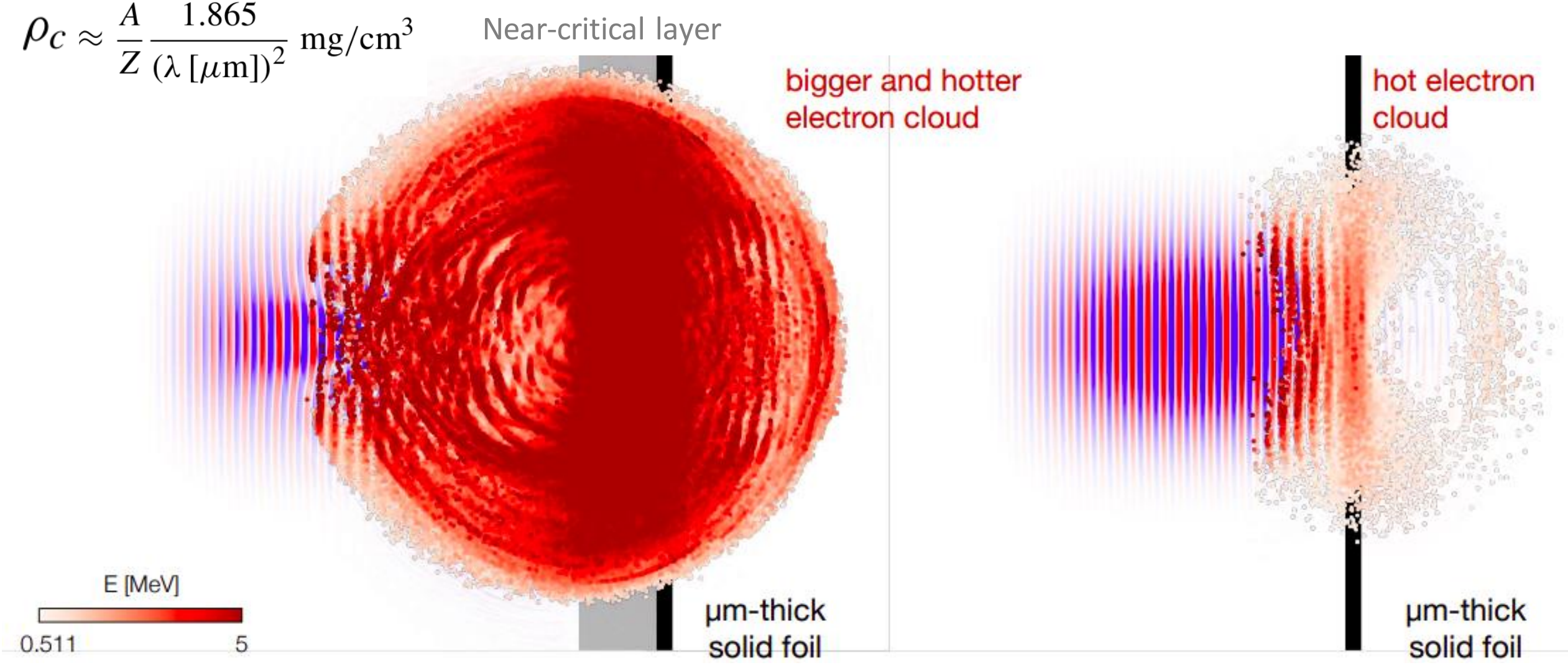

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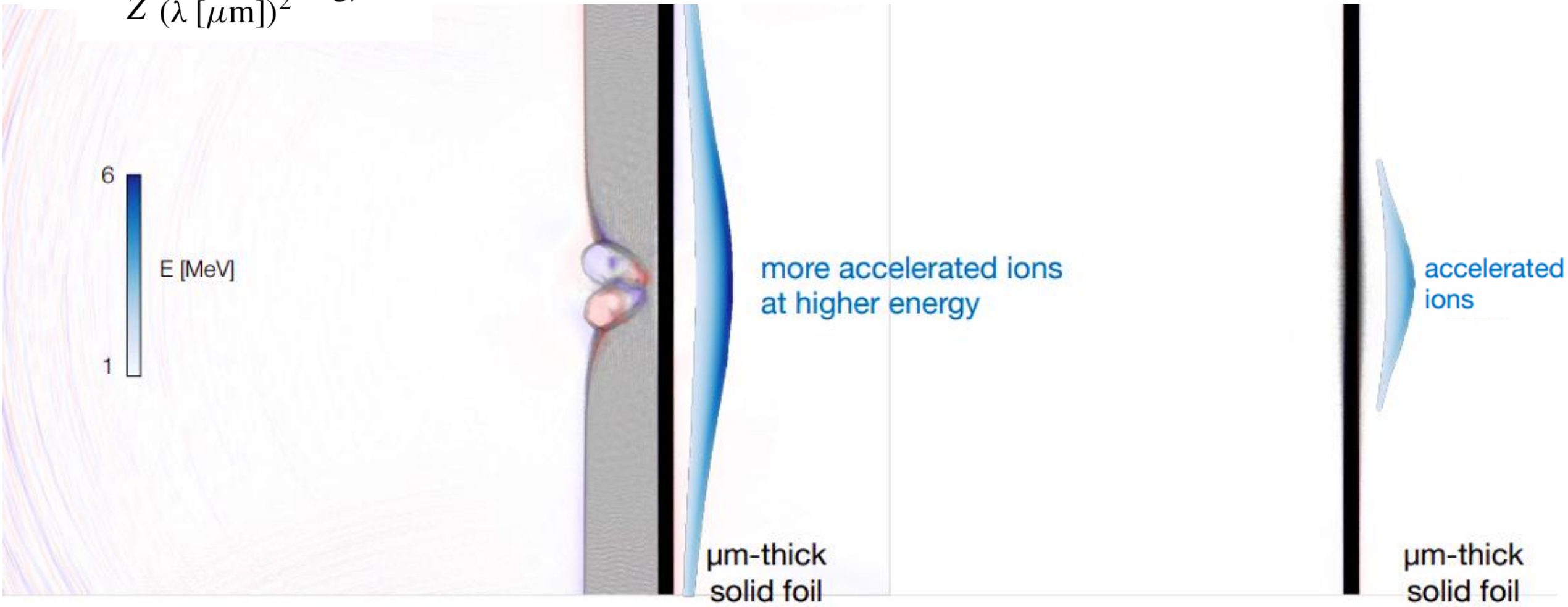
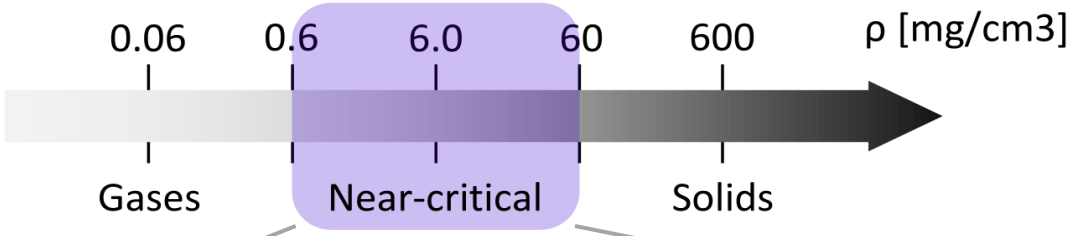
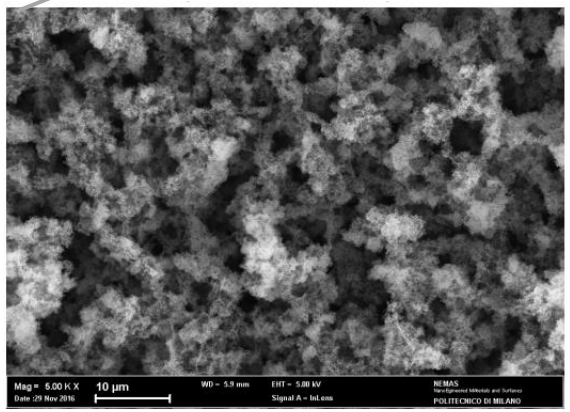
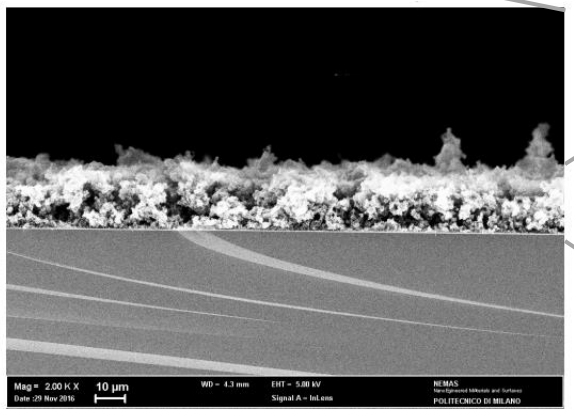


# How to make double layer-targets?

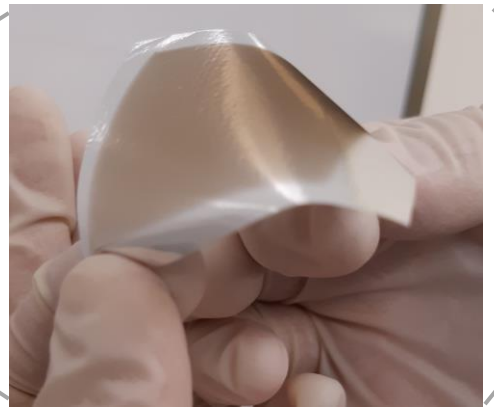


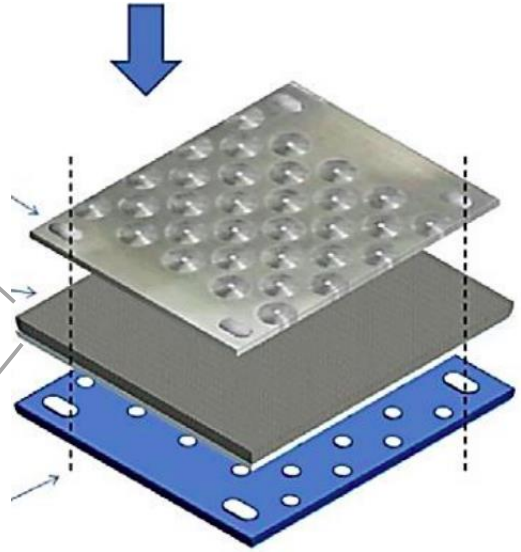

**Carbon Nanofoams**





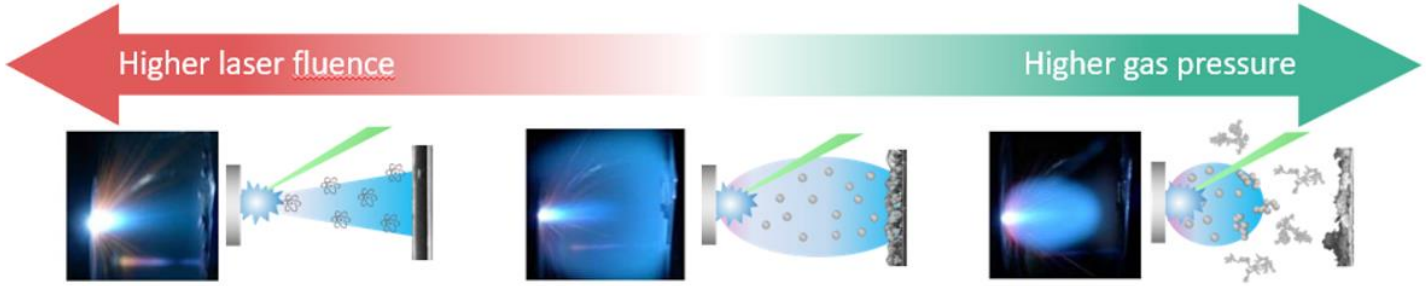
~10 µm carbon nanofoam on a micrometric Ti foil





Overall target assembly

Produced by **Pulsed Laser Deposition**




I. Prencipe, et al., Plasma Phys. Control. Fus. 58 (2016) 034019
A. Maffini, et al., Phys. Rev. Materials 3 (2019) 083404

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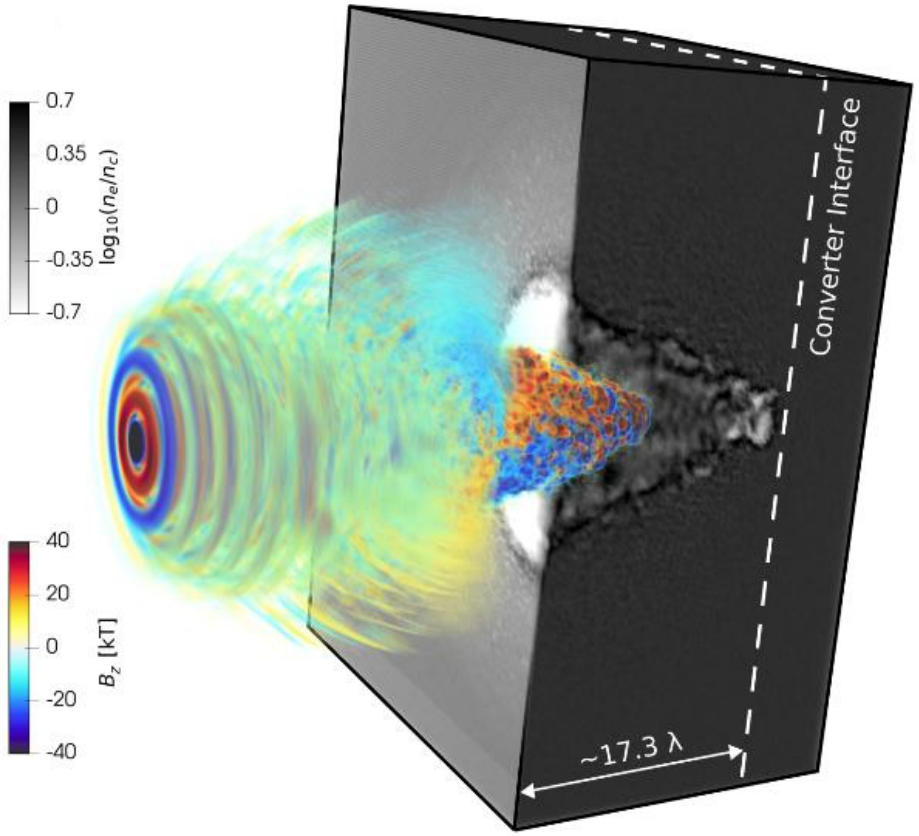
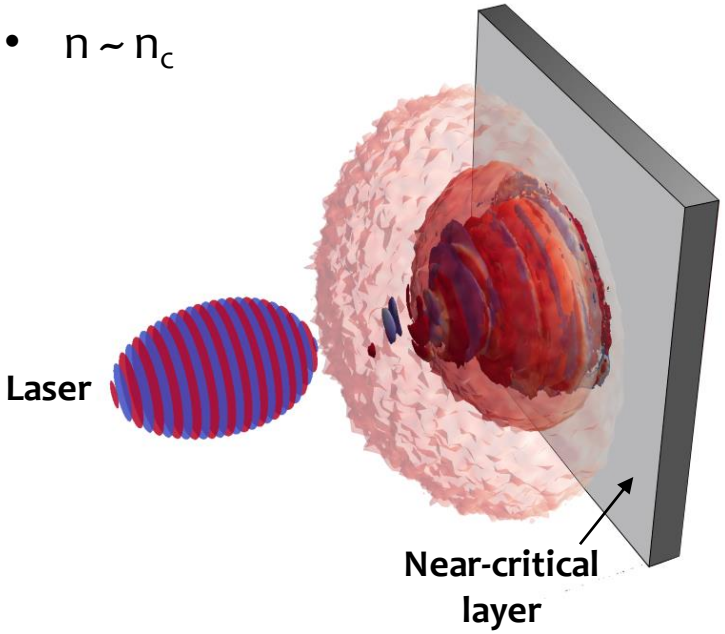
# Laser-driven Photon Activation Analysis

## 1) Laser interaction with near-critical material → Hot e- generation



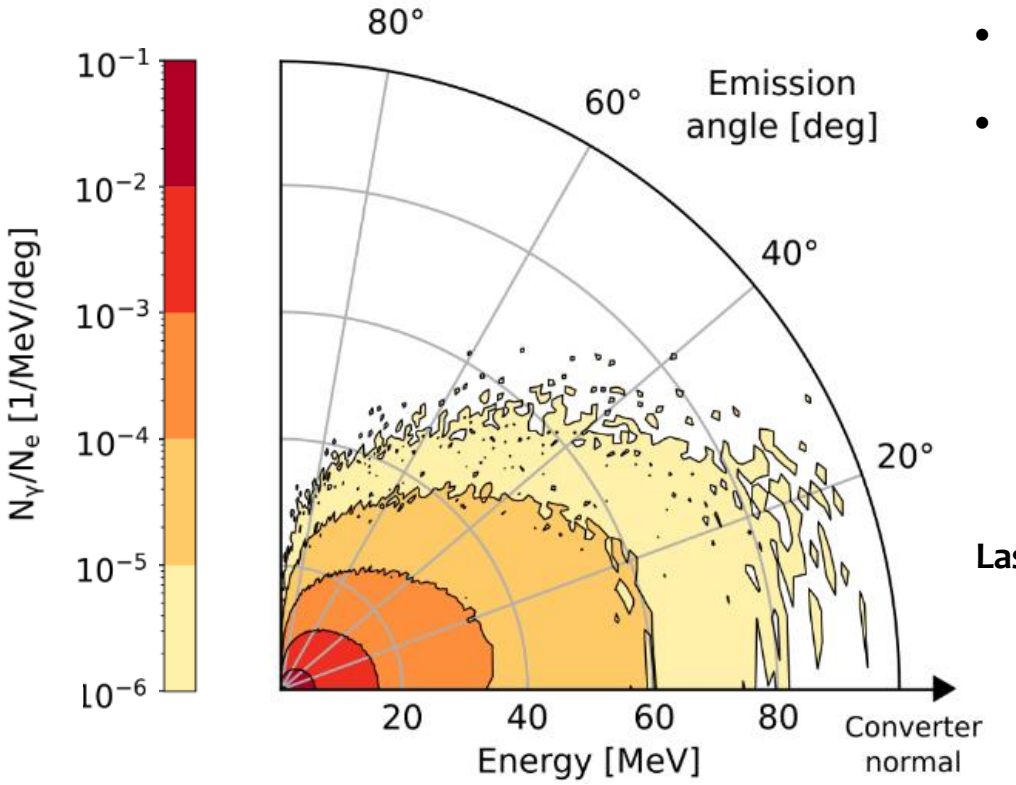

- $a_0 = 20$
- 10 μm foam
- $n \sim n_c$



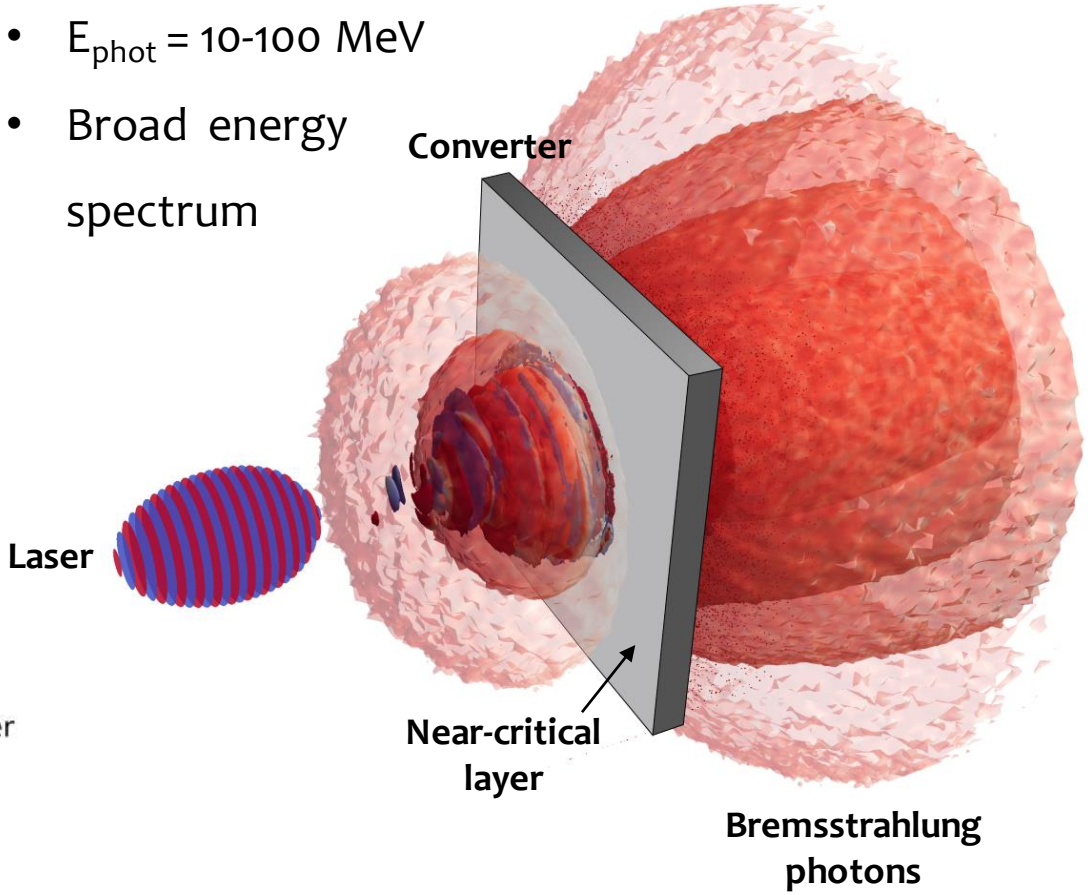

Mirani, F., et al. "Superintense Laser-driven Photon Activation Analysis." Communications Physics 4, 185 (2021)

# Laser-driven Photon Activation Analysis

**2)** **Hot e-** interaction with **mm-thick substrate** → Bremsstrahlung **photons** generation



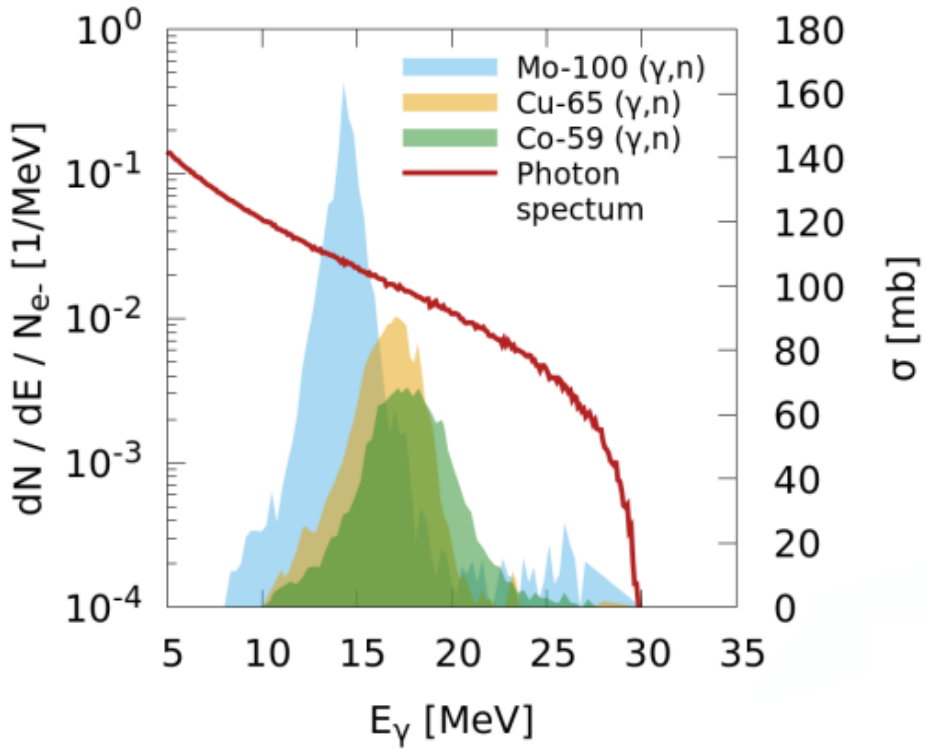

- $E_{phot}$ = 10-100 MeV
- Broad energy spectrum



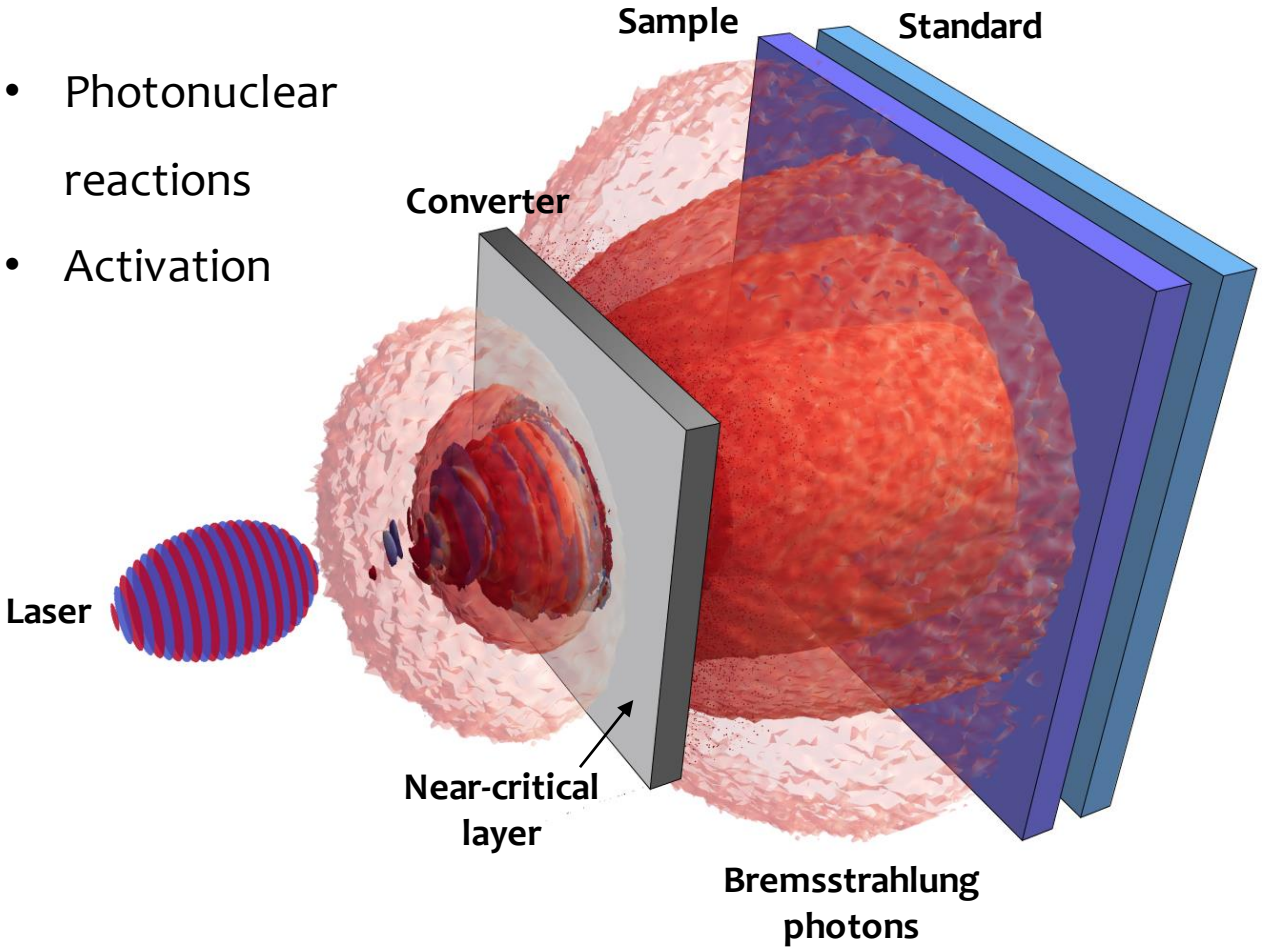

Mirani, F., et al. "Superintense Laser-driven Photon Activation Analysis." Communications Physics 4, 185 (2021)

# Laser-driven Photon Activation Analysis

## 3) Irradiation of sample and reference material




- Photonuclear reactions
- Activation

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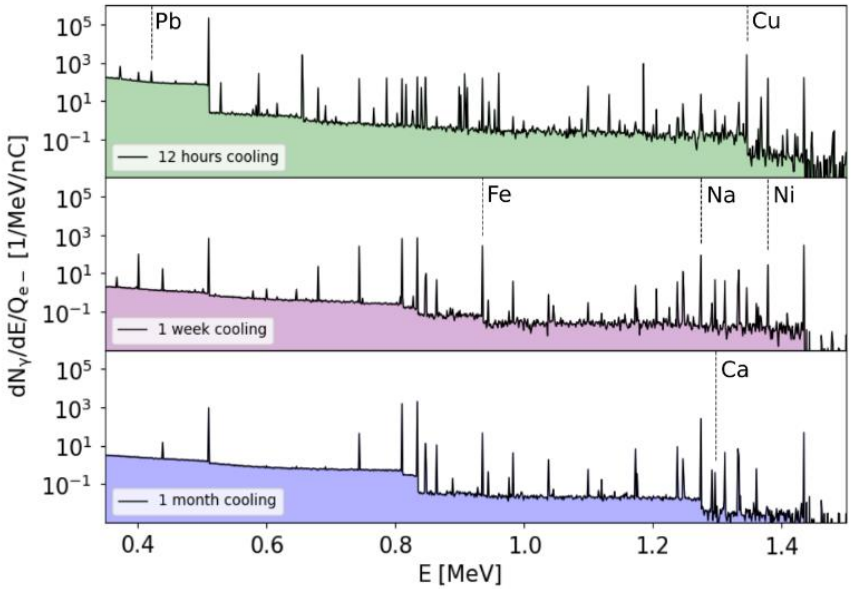
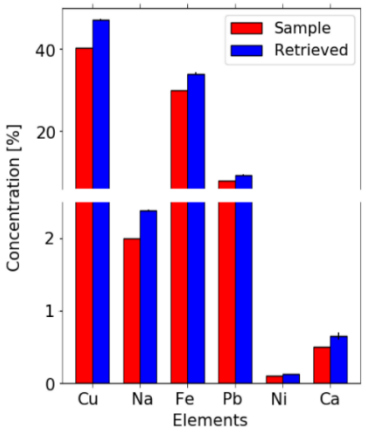
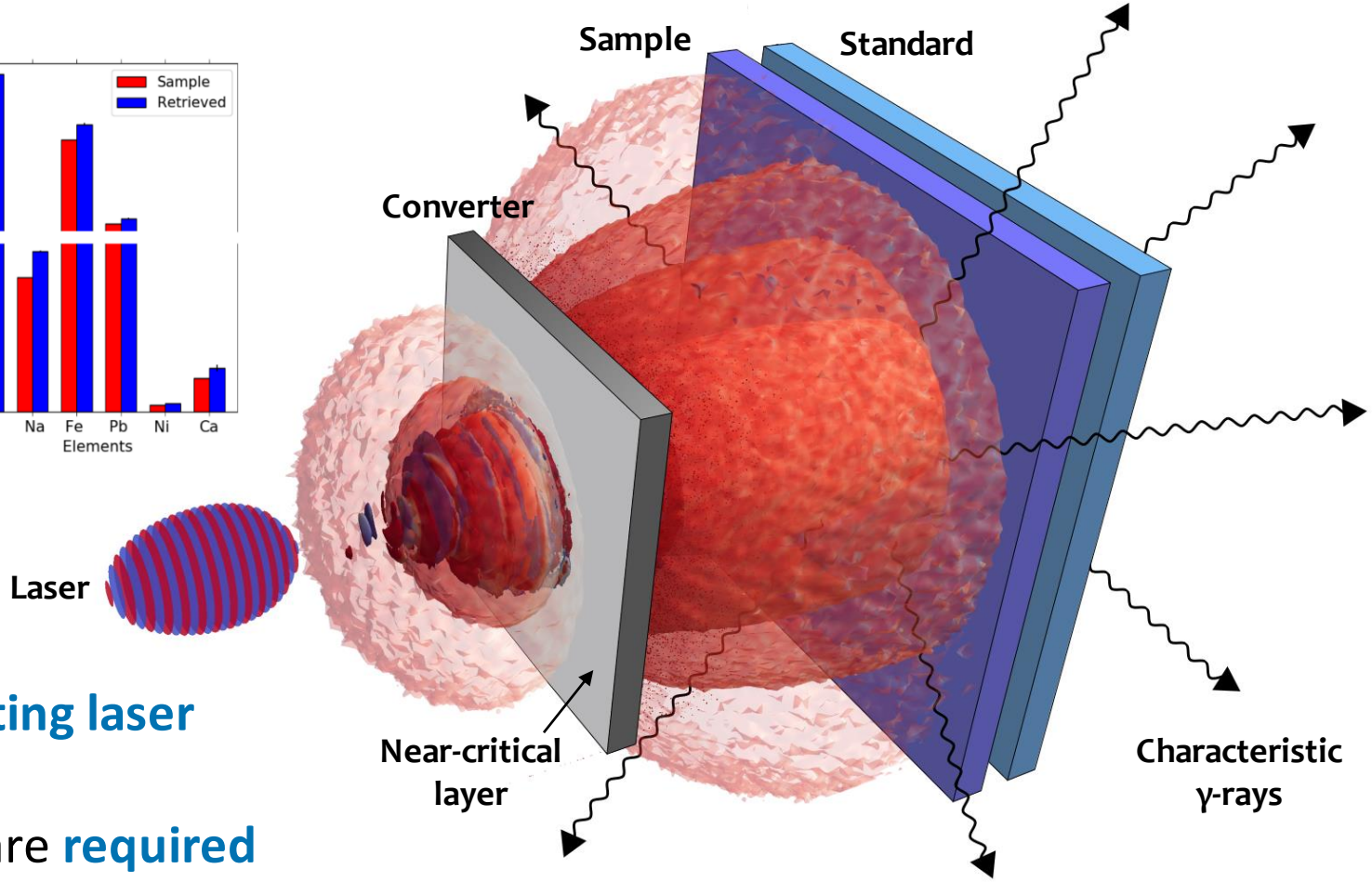
# Laser-driven Photon Activation Analysis

4) Delayed emission of **characteristic γ-rays** → **Composition** reconstruction



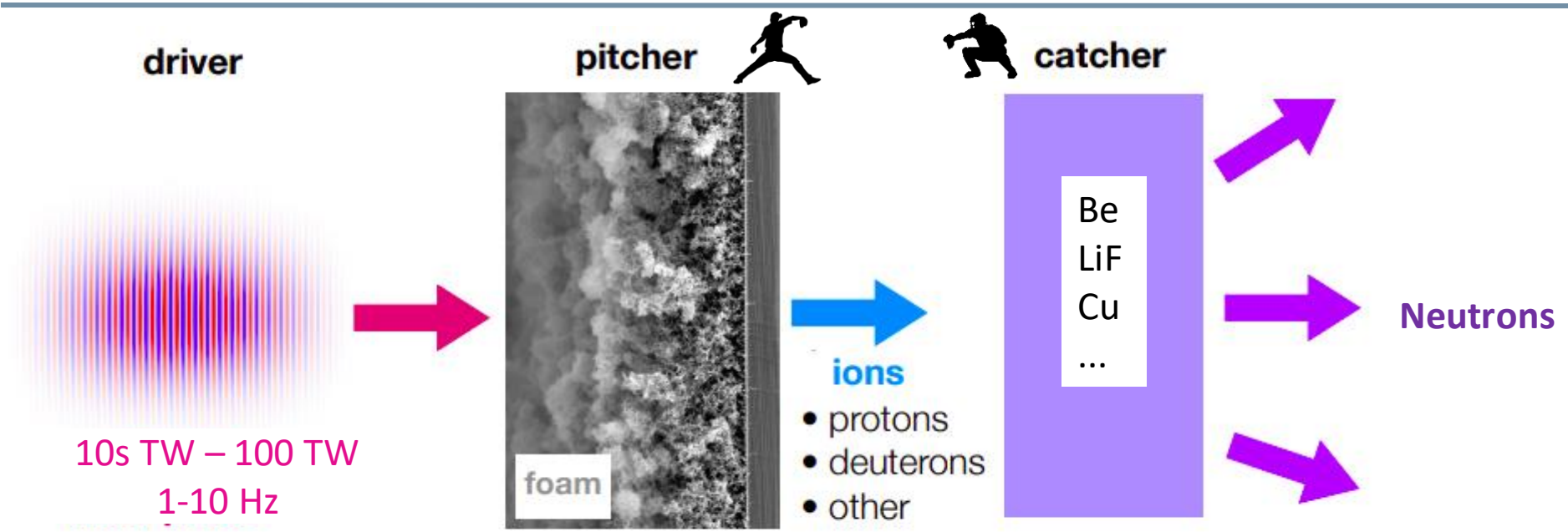

- Laser-driven **PAA achievable** with **existing laser** technology
- Near-critical targets + **100s TW** lasers are **required**

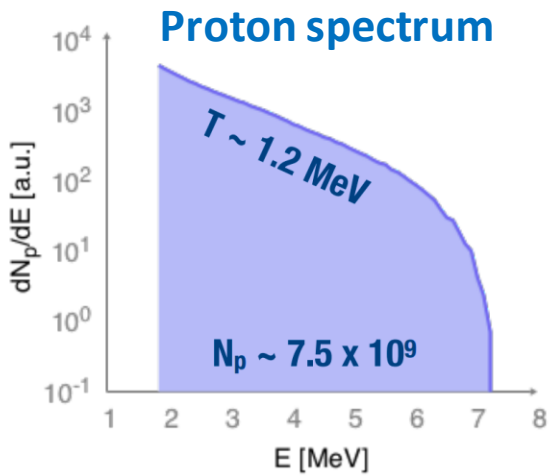
Mirani, F., et al. "Superintense Laser-driven Photon Activation Analysis." Communications Physics 4, 185 (2021)

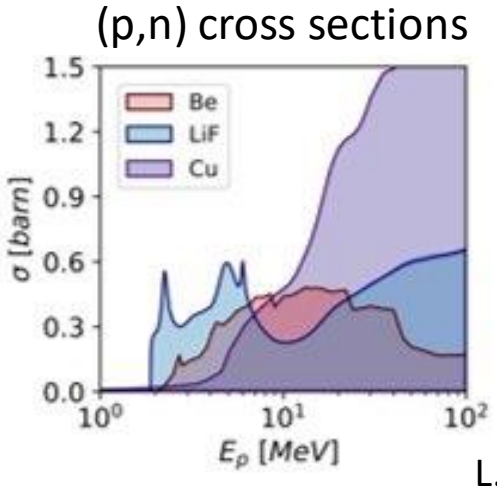
# Outline:

- What is Laser-Driven Acceleration (and why) ?
- Case study 0: Laser-Driven Proton Induced X-ray Analysis
- Why Double-Layer Targets (DLTs)?
- Case study 1: Photon Activation Analysis with DLTs
- **Case study 2: Fast Neutron Resonance Radiography with DLTs**
- Conclusion

# Compact laser-driven neutron generation with DLT




L. Fedeli, et al., New Journal of Physics 22, 033045 (2020)

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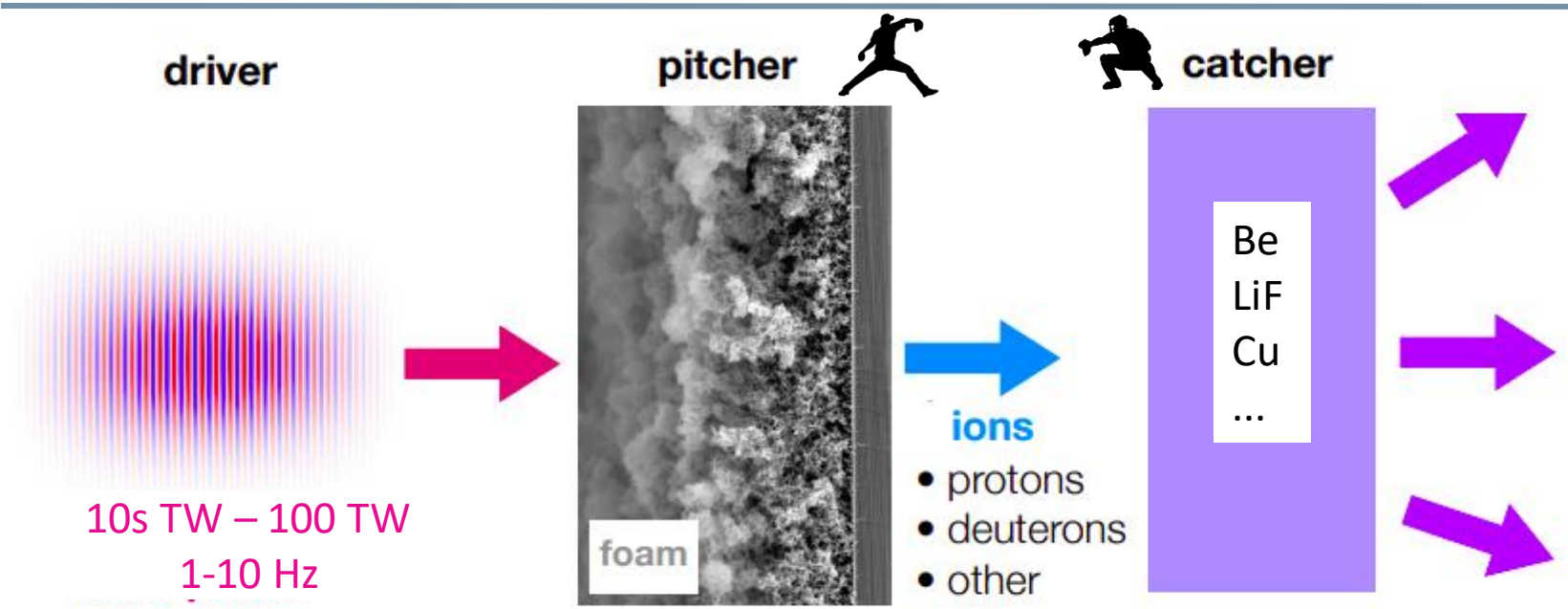
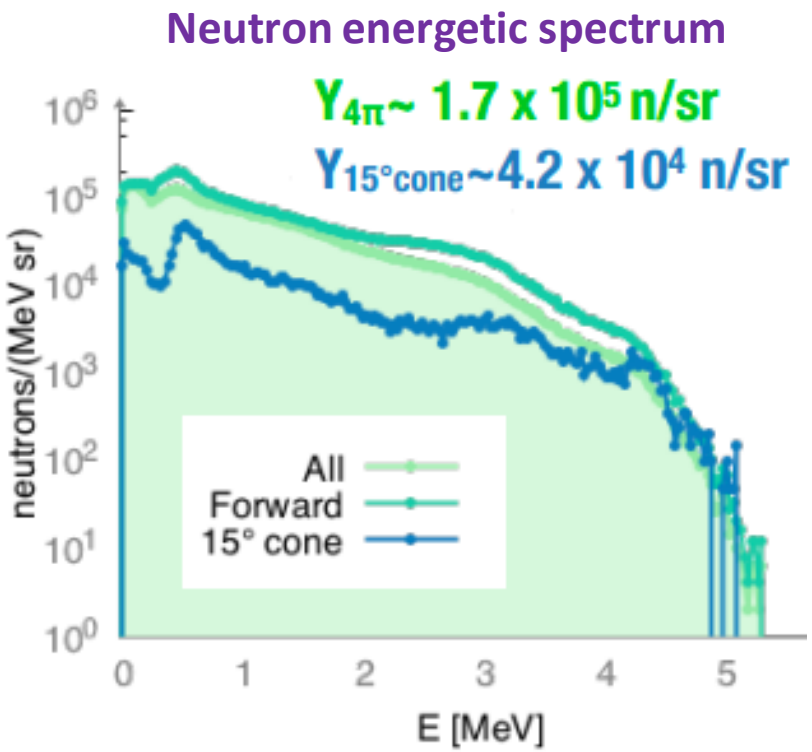
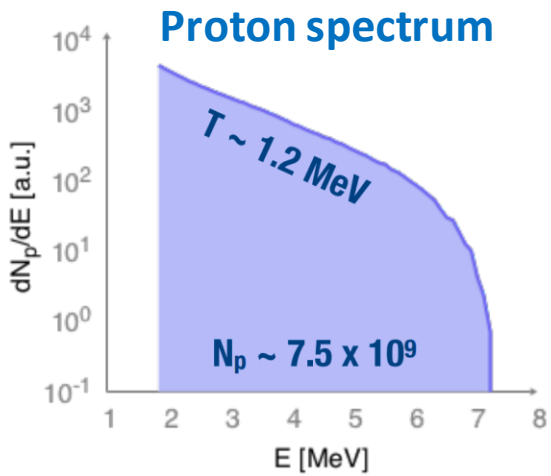
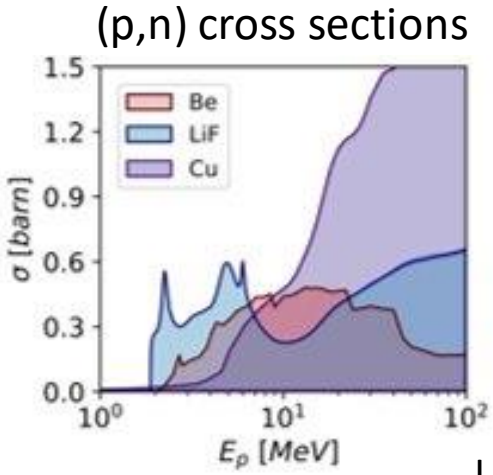


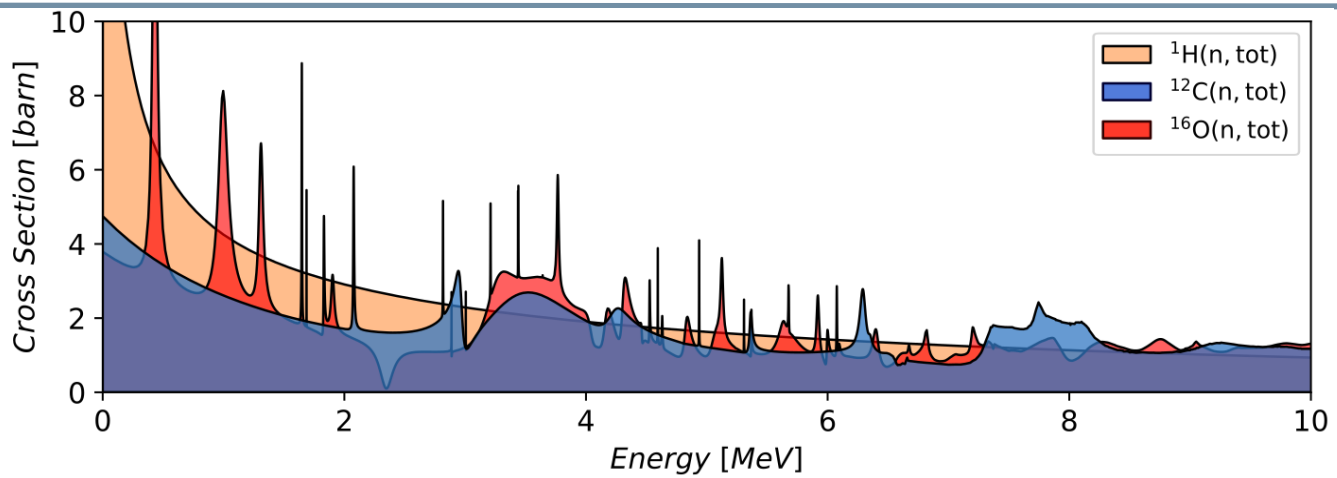

Conditions:
PIC + MonteCarlo Simulation
20 TW pulse (a0=3)
DLT: 4 µm foam ~1 $n_c$
LiF catcher, 1 mm

L. Fedeli, et al., New Journal of Physics 22, 033045 (2020)

# Laser-driven Fast Neutron Reaction Radiography

**Fast Neutron Resonance Radiography (FNRR)**

- Detection and imaging of H, O, N and C (Relevant for drug & explosives )
- ≥ $10^4$ n/cm$^2$/s at ≥ 3 m distance
- Broad spectrum, 1-10 MeV



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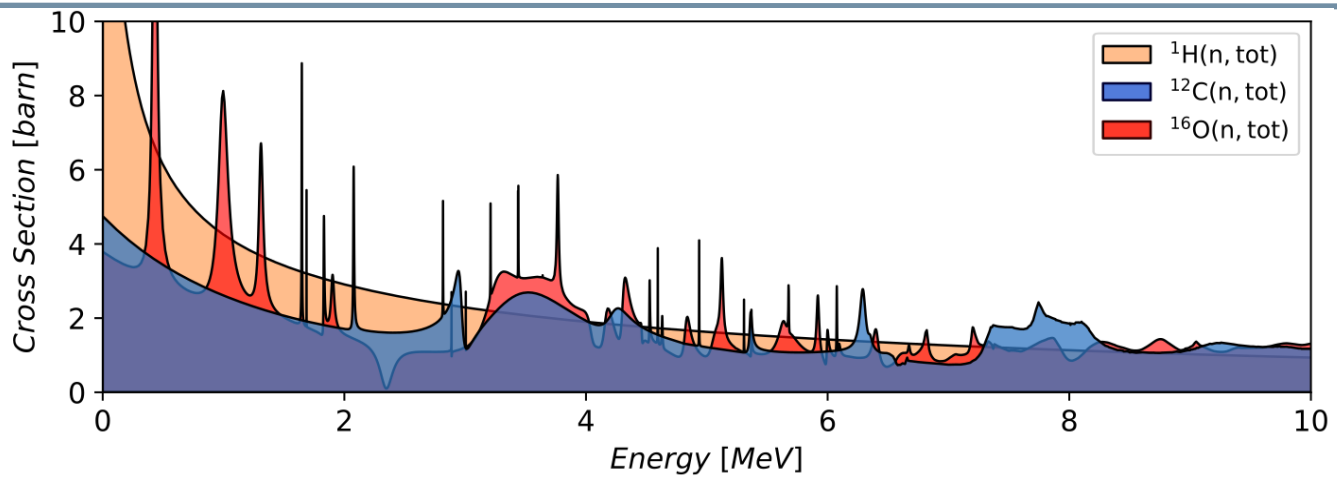
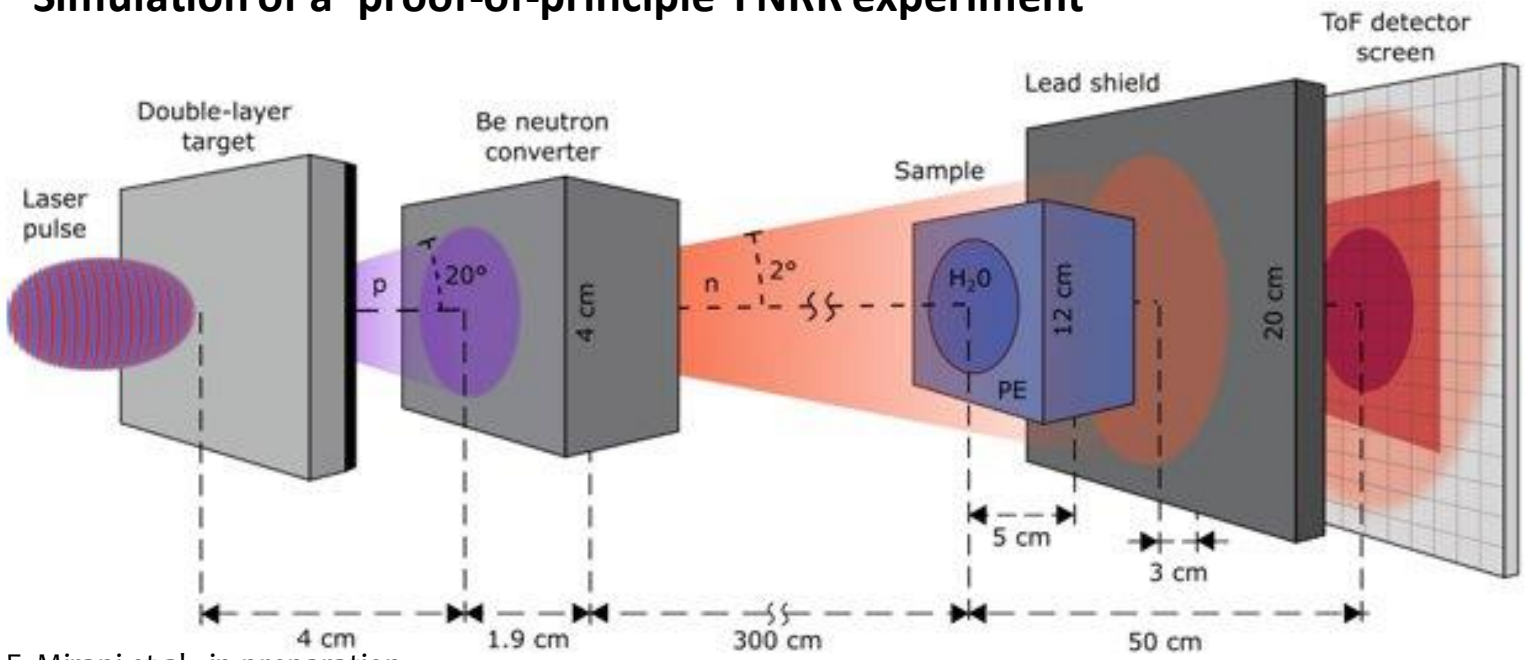



**Simulation of a 'proof-of-principle' FNRR experiment**

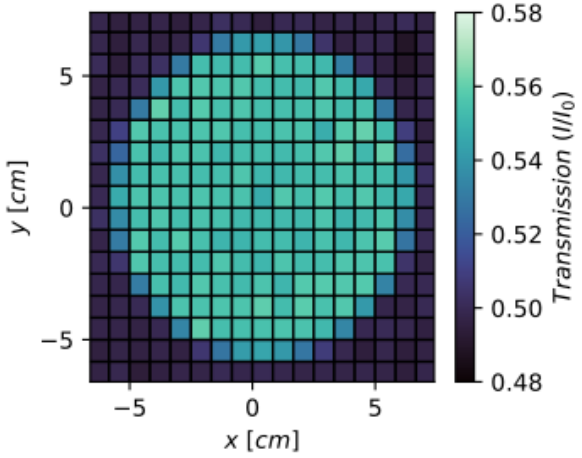



F. Mirani et al., in preparation

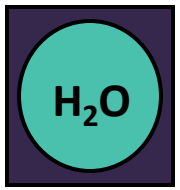
- PW class laser (**$a_0$ = 10 - 20, 5 Hz)**
- **DLT:** 8 µm foam, ~3 nc
- Catcher: 19 mm **Be**
- Samples: **$H_2O$** + polythene & **$C_{10}H_{15}N$** + steel
- **Lead shield** ~30 mm to shield x-rays
- **Pixelated ToF detector**

# Laser-driven Fast Neutron Reaction Radiography

**Transmission**

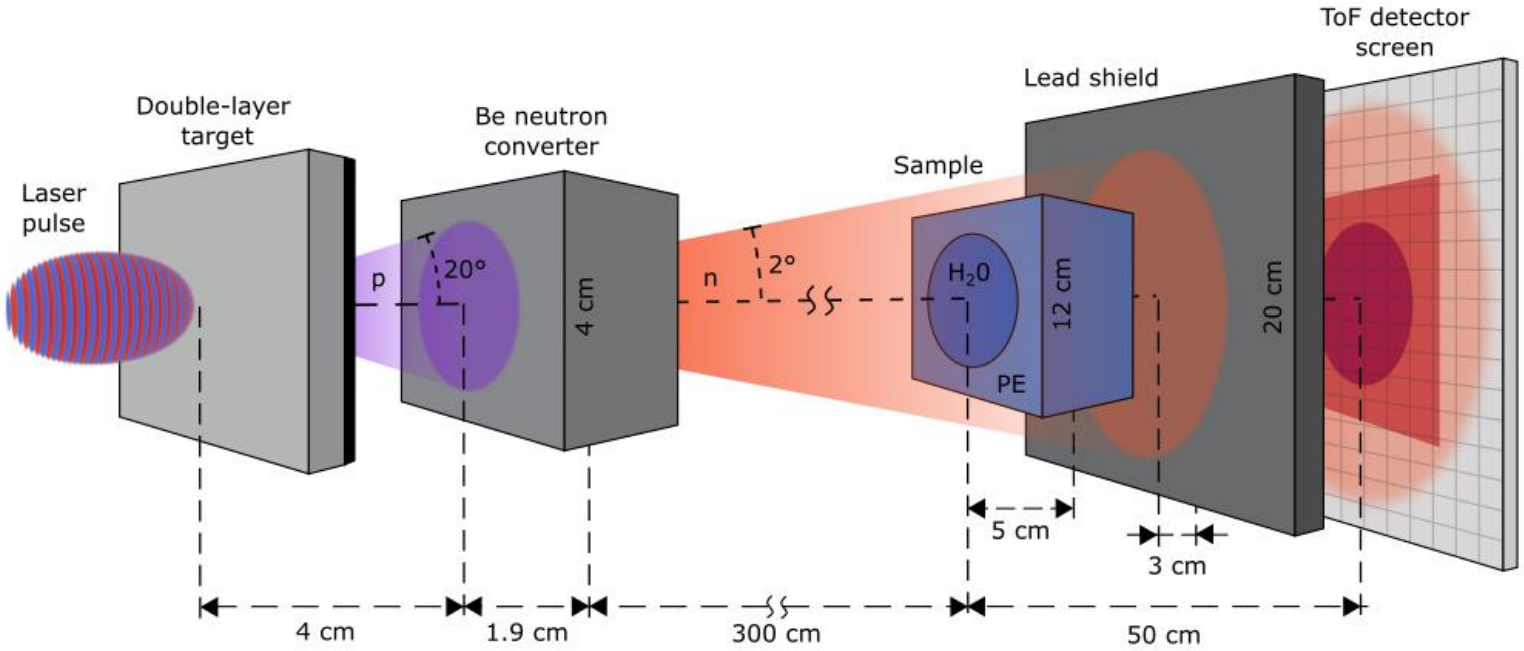



**$(C_2H_4)_n$**



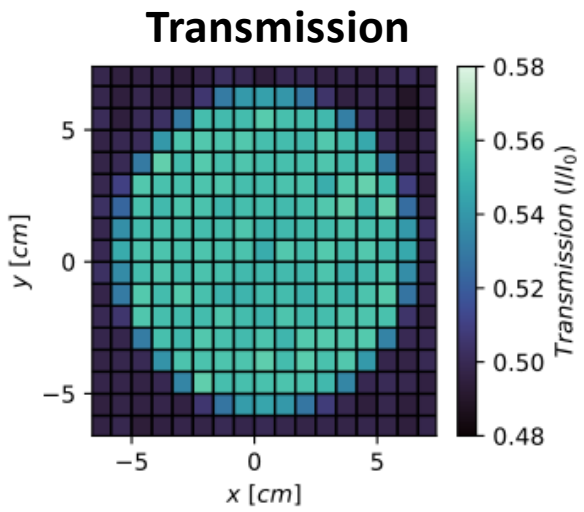

**Imaging**

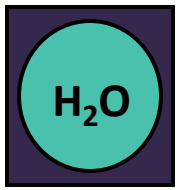
Does not discriminate elements




F. Mirani et al., in preparation

# Laser-driven Fast Neutron Reaction Radiography

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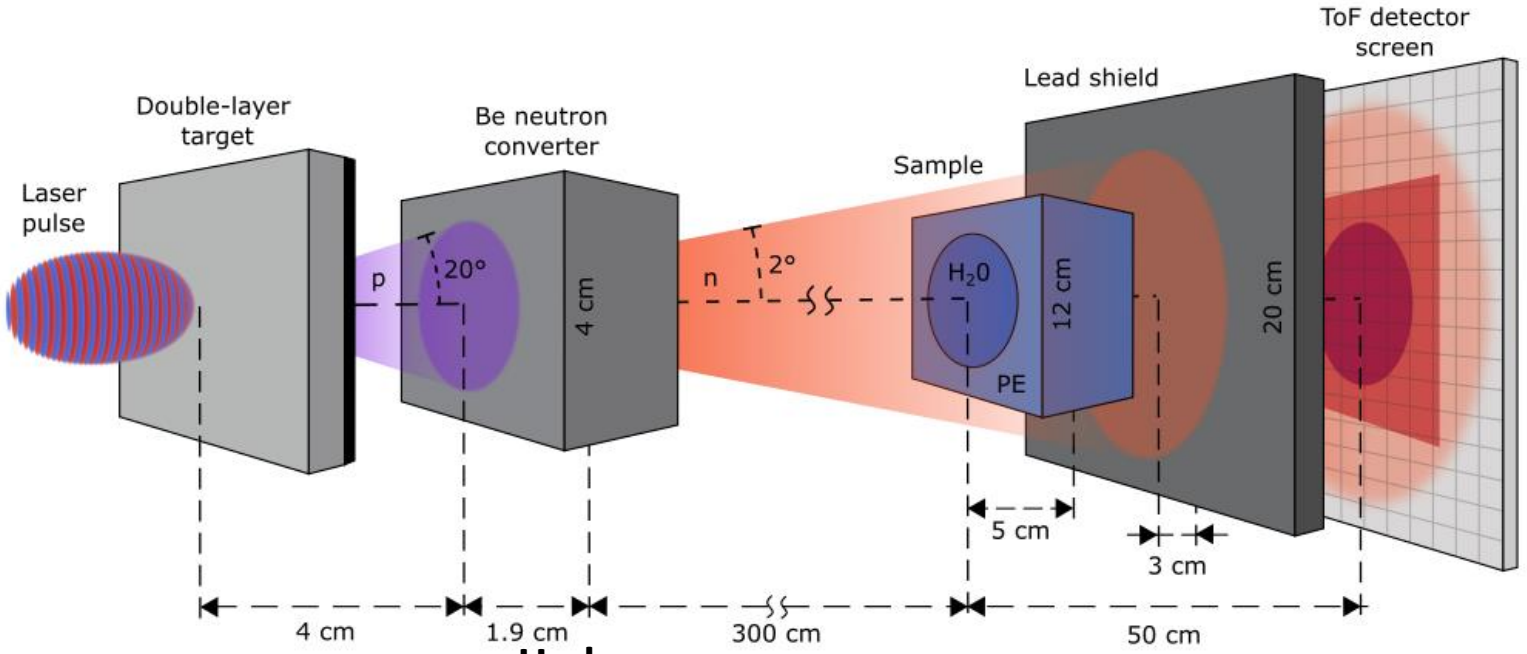


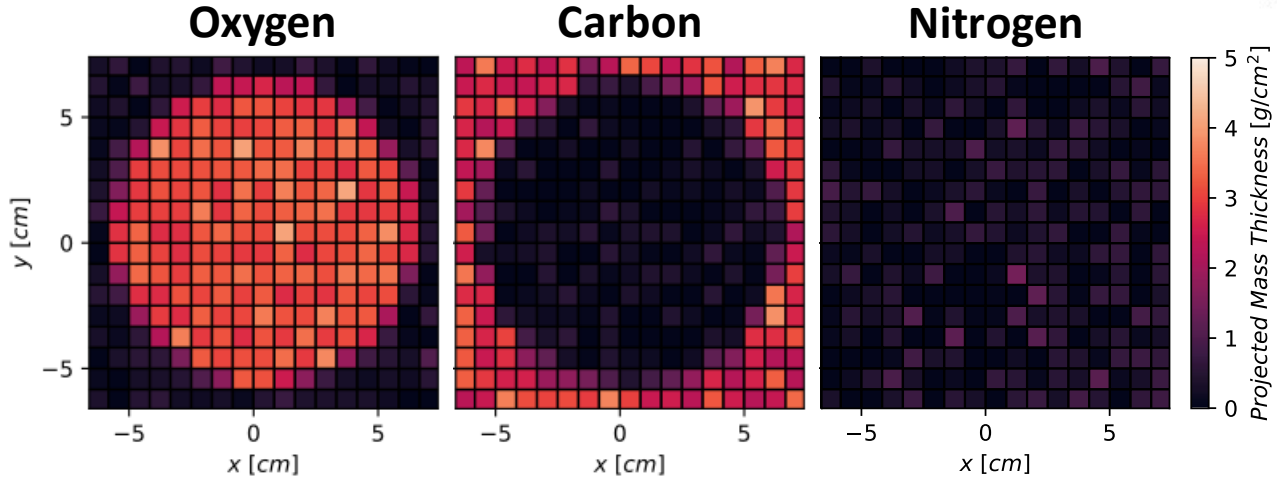


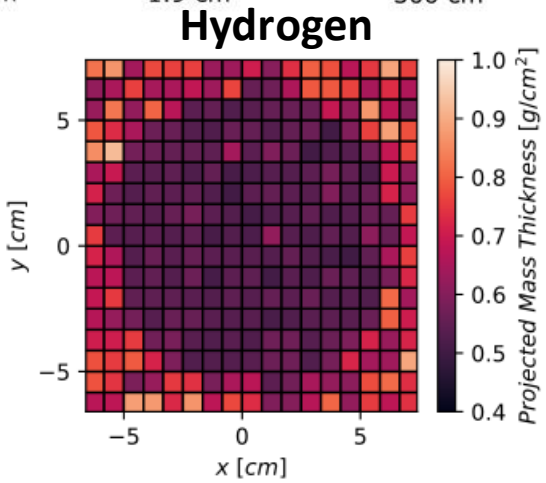


- 1 min irradiation at 5 Hz
- ~$10^{11}$ n/sr total

**Elemental Imaging Achieved**

F. Mirani et al., in preparation

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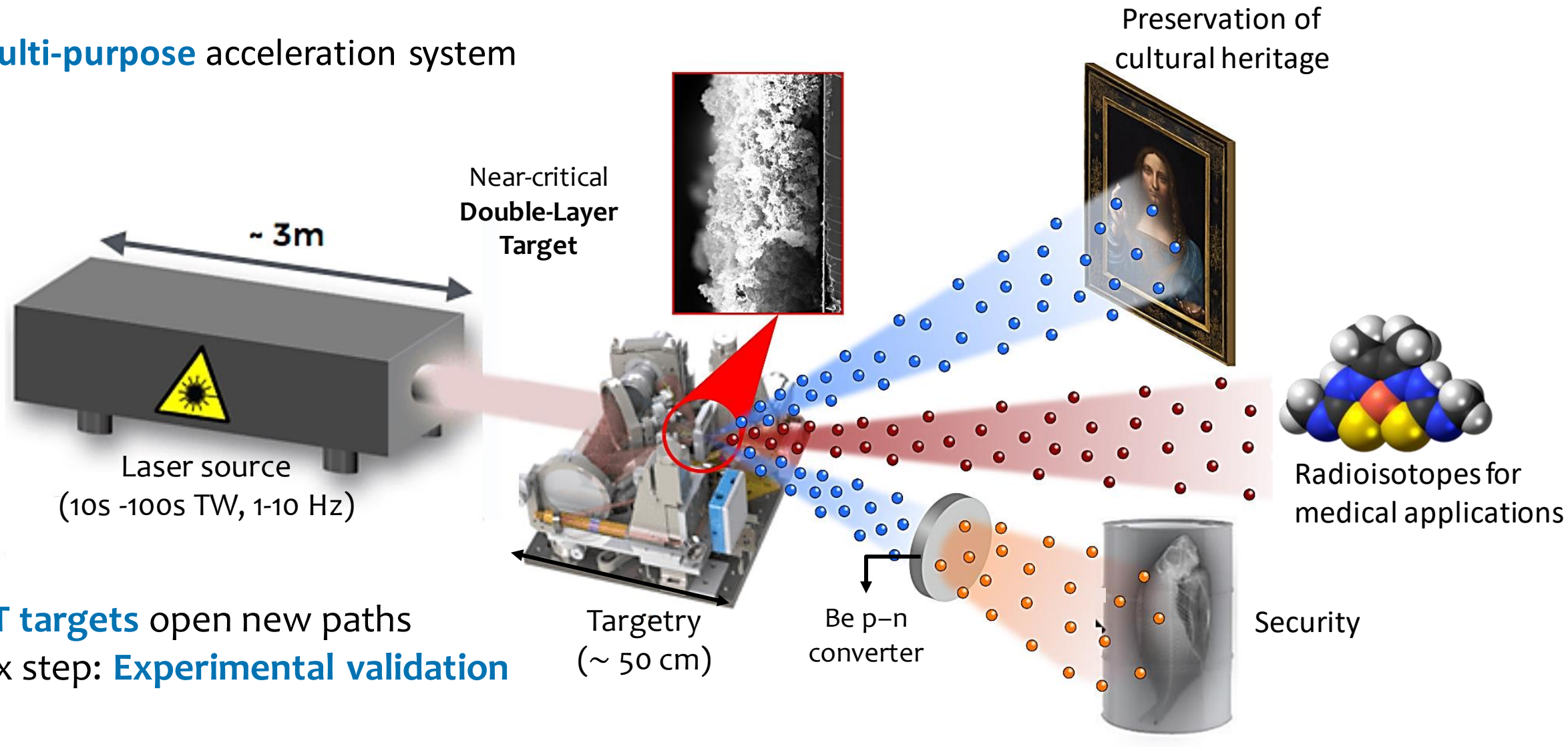
- **Conclusion**

# Conclusions and perspectives

- **Multi-purpose** acceleration system




- **DLT targets** open new paths
- Nex step: **Experimental validation**

# Thank you

ERC-2014-CoG No. 647554
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NanoLab
Department of Energy

Acknowledgements:
- ENSURE - ERC Consolidator Grant
- INTER - ERC Proof-of-Concept Grant
- PANTANI - Proof-of-Concept Grant

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