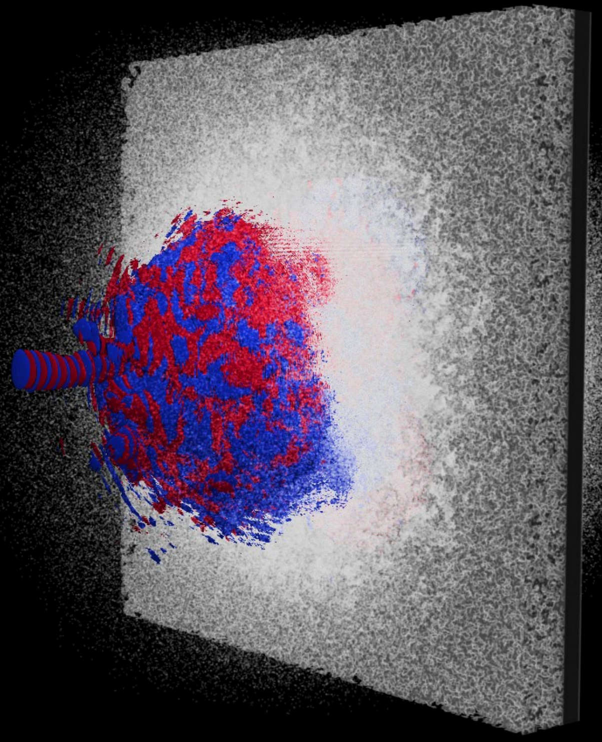
50th Conference of Plasma Physics

Beam Plasmas & Inertial Fusion

Laser-driven ion acceleration and neutron generation from near-critical plasmas exploiting nanostructured targets and the VEGA-3 laser

Francesco Mirani



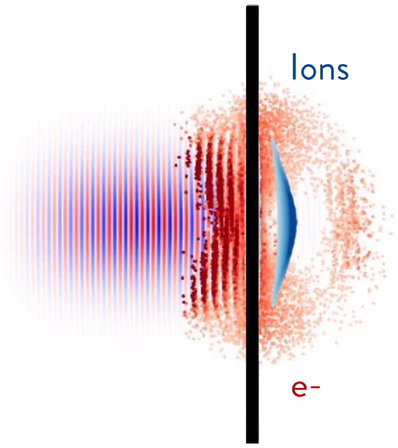
POLITECNICO MILANO 1863

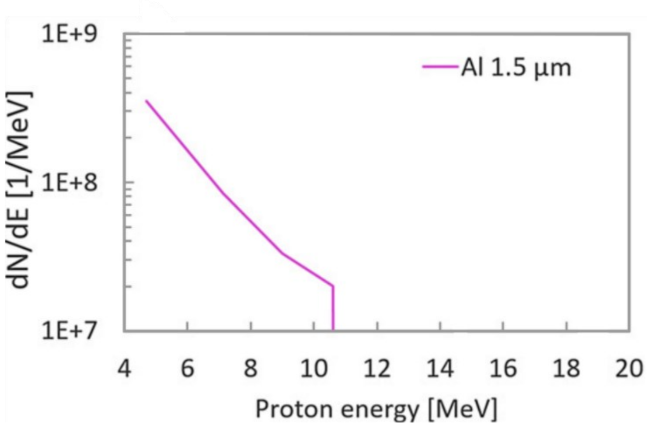
EUROPEAN PHYSICAL SOCIETY

Infraestructuras Científicas y Técnicas Singulares

CLPU CENTRO DE LÁSERES PULSADOS

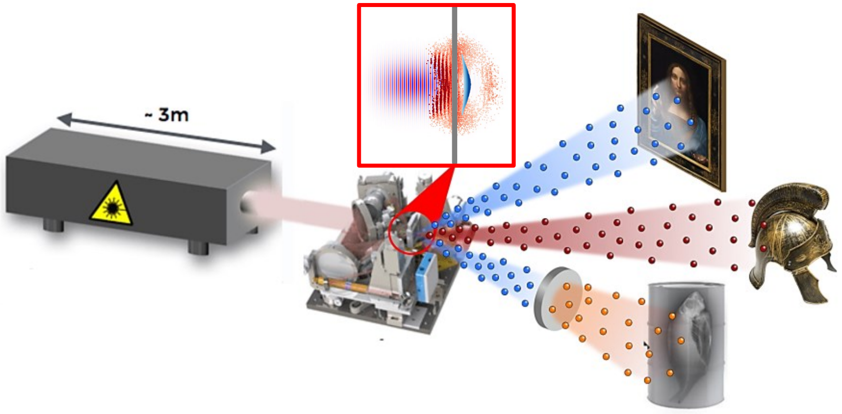
Laser-driven particle acceleration from solid targets: motivations of the work





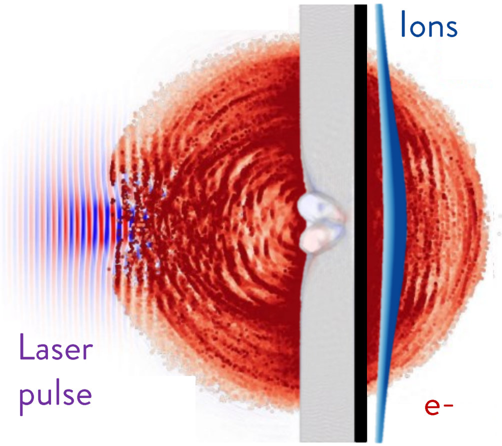
- Emission of **electrons** and **ions.**
- **10^9 - 10^{12} protons/shot** accelerated (depending on laser and target properties).
- Important **limitations** subject of active research:
  - Improve shot-to-shot **stability** ← Affected by thickness uncertainty in **commercial targets**
  - Need for **reliable diagnostics** with absolute calibration and real-time monitoring

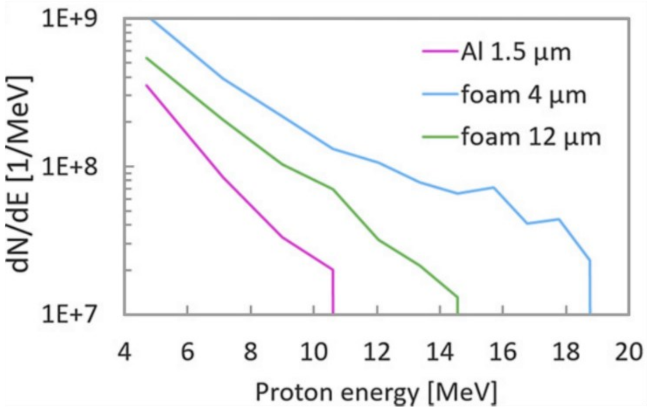
- Many potential appealing features!
  - Compact
  - Energy tunability (**flexibility**)
  - Cheap
  - Multiple radiation fields → **multi-purpose**
- Attractive for **several applications.**



A. Macchi, et al. *RMP* 85.2 (2013): 751-793.
I. Prencipe, et al. *New J. Phys.* 23.9 (2021): 093015.
M. Passoni, et al. *PPCF* 62.1 (2019): 014022.

Laser-driven particle acceleration from solid targets: motivations of the work





- Many potential appealing features!

Compact

Energy tunability (**flexibility**)

Cheap

Multiple radiation fields → **multi-purpose**

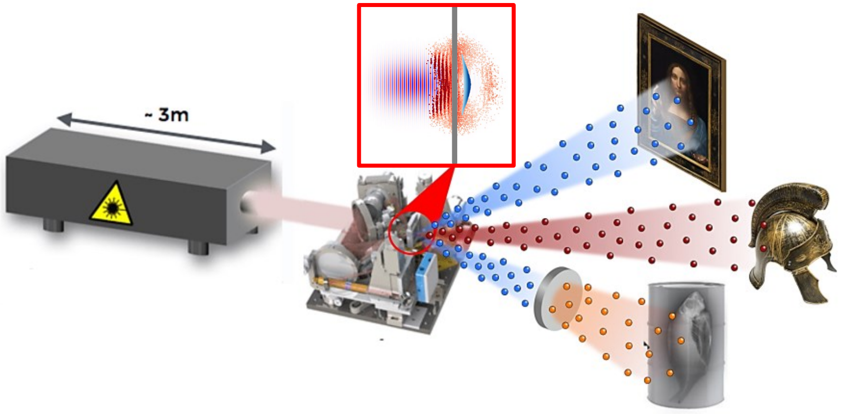
- Near-critical Double-Layer Target (**DLT**) → **Increase** the **energy** and **number** of the particles → Mitigate laser requirements.

- Important **limitations** subject of active research:

  Improve shot-to-shot **stability** ← Affected by thickness uncertainty in **commercial targets**

  Need for **reliable diagnostics** with absolute calibration and real-time monitoring

- Attractive for **several applications.**



A. Macchi, et al. *RMP* 85.2 (2013): 751-793.

I. Prencipe, et al. *New J. Phys.* 23.9 (2021): 093015.

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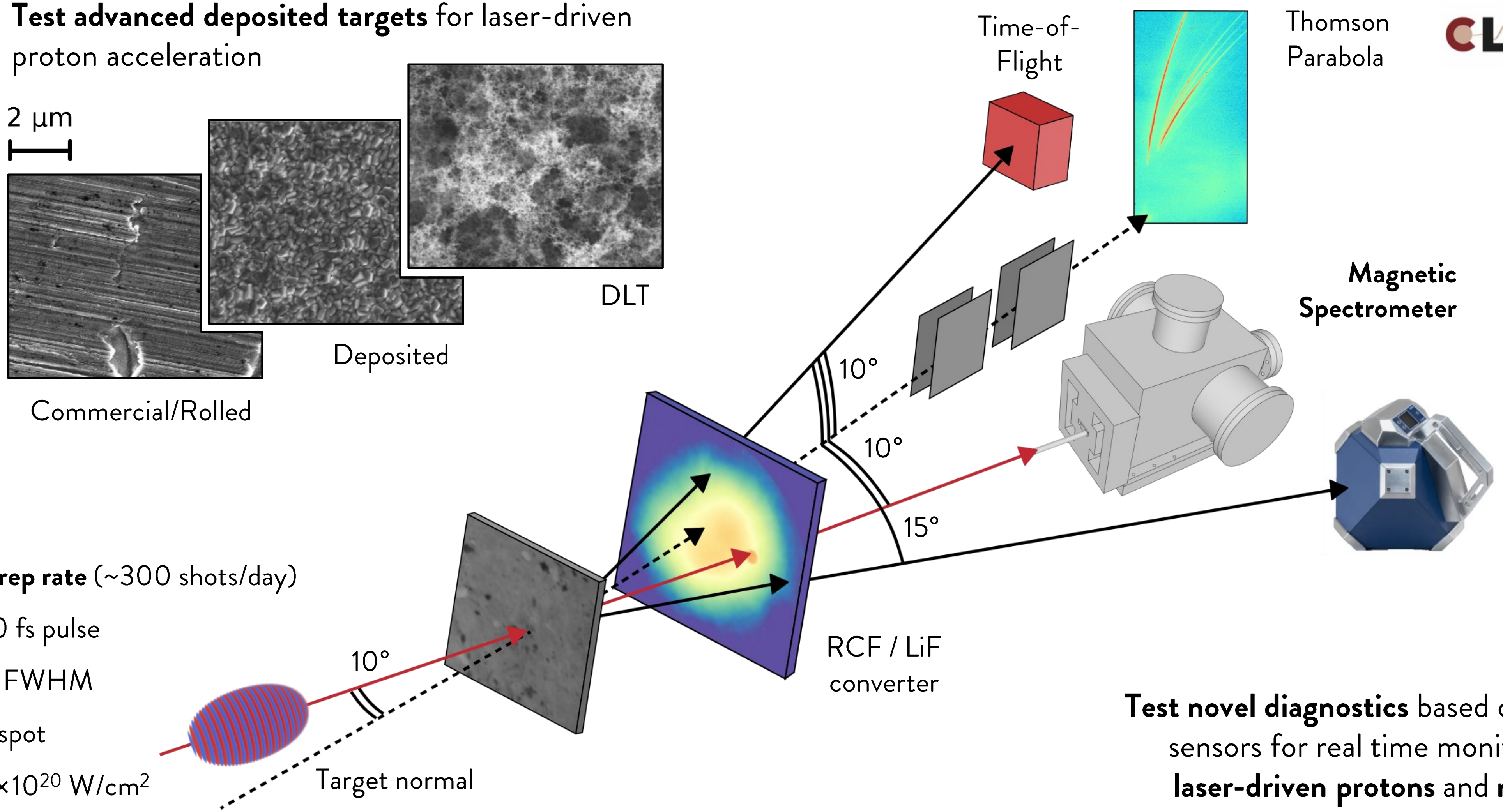
Goals and setup of the experimental campaign with VEGA-3 @ CLPU

1 **Test advanced deposited targets** for laser-driven proton acceleration



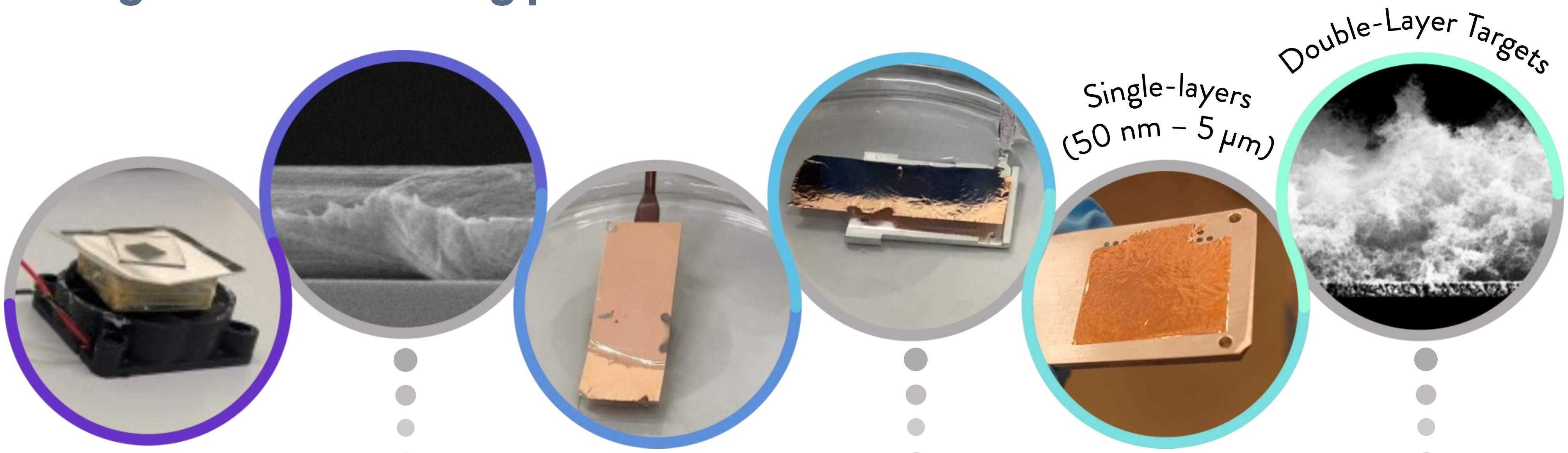
VEGA-3

- **High-rep rate** (~300 shots/day)
- 30-50 fs pulse
- 12 um FWHM
- 4 J in spot
- ~1.25×10^{20} W/cm^2

2 **Test novel diagnostics** based on active sensors for real time monitoring of **laser-driven protons** and **neutrons**

L. Roso EPJ *Web of Conferences*. Vol. 167. EDP Sciences, 2018.

Deposited target manufacturing procedure



Spin coated soap layer on wafer

HiPIMS **Al-substrate deposition**

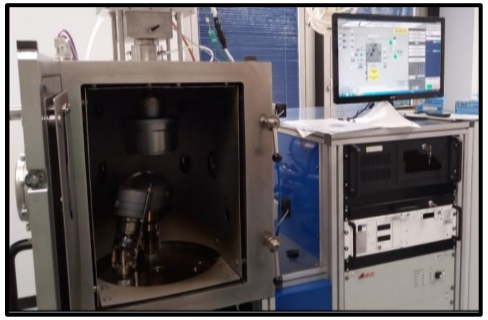
Dissolution in water

Fishing of the film

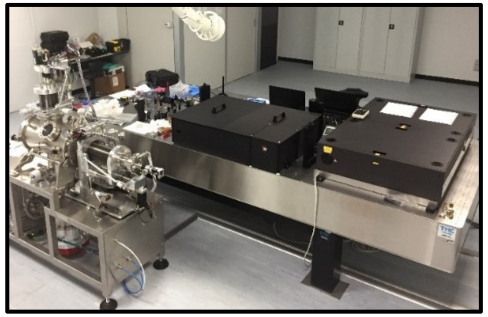
Free-standing **film**

PLD **C-foam deposition**

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



Pulsed-Laser Deposition (**PLD**)



Facilities @ Politecnico

A. Maffini, et al. *EPJ tech. instrum* 10.1 (2023): 15.

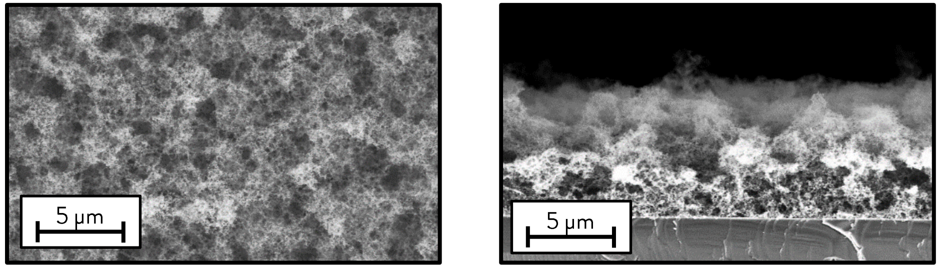
A. Maffini, et al. *Appl. Surf. Sci* 599 (2022): 153859.

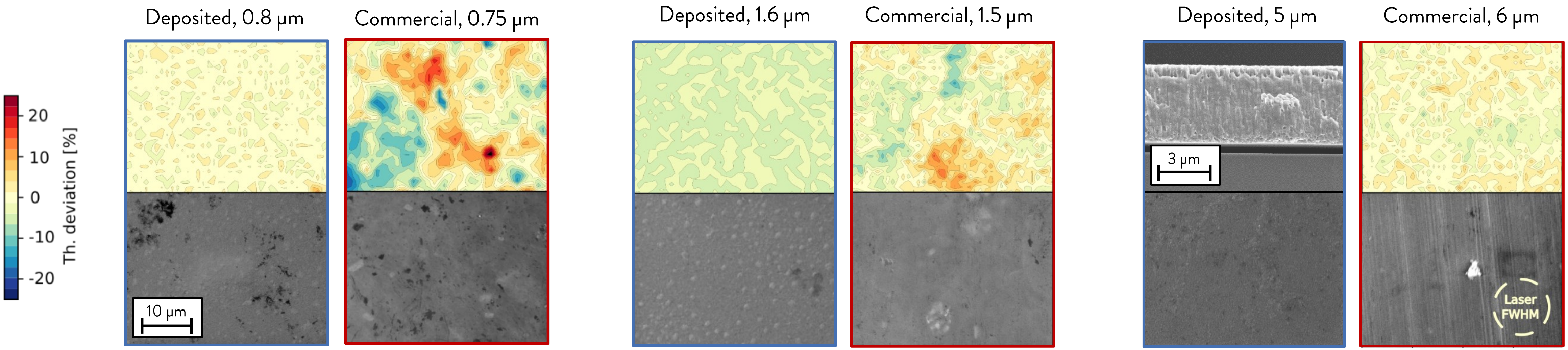
Deposited targets characterization and comparison with reference commercial foils

- **Thickness uniformity** determined with EDXS maps and SEM cross sections of Al-deposited films.
- Deposited Al foils (0.8 – 5 μm):
  - Max ± **5% local deviation** from nominal thickness.
- Commercial Al foils (0.75 – 12 μm):
  - Real average thicknesses ≠ nominal (up to 40 %).
  - Max ± **25% local deviation** from the average thickness

- DLTs with **1.6 μm** and **6 μm** substrates
- Carbon foam thicknesses **9-54 μm**
- Average density **~ 6.4 mg/cm³**

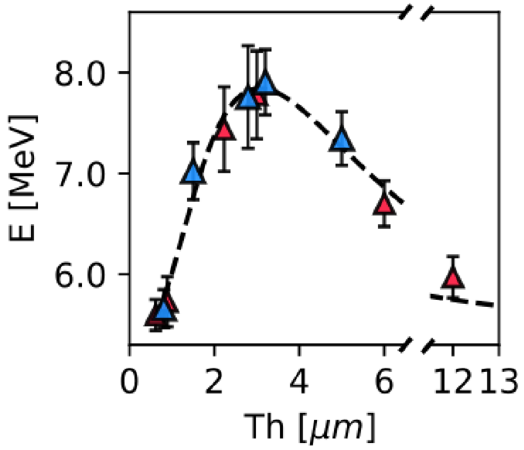
Carbon foam, 9 μm



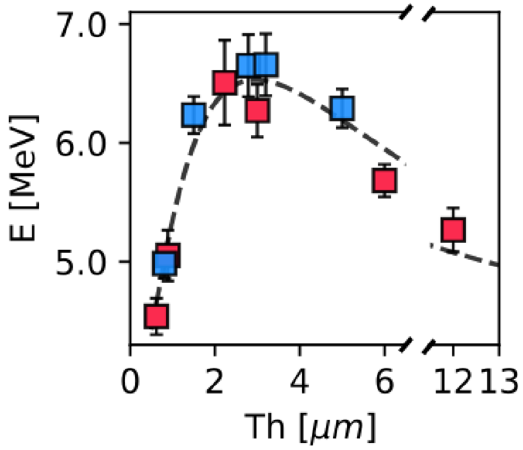


Proton acceleration from deposited and commercial single-layer targets

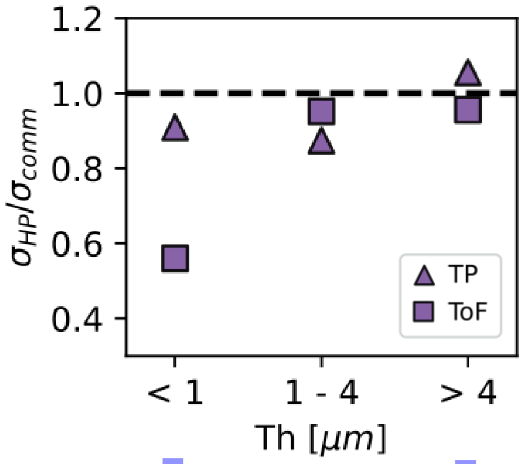
Maximum Energy
(Thomson Parabola)



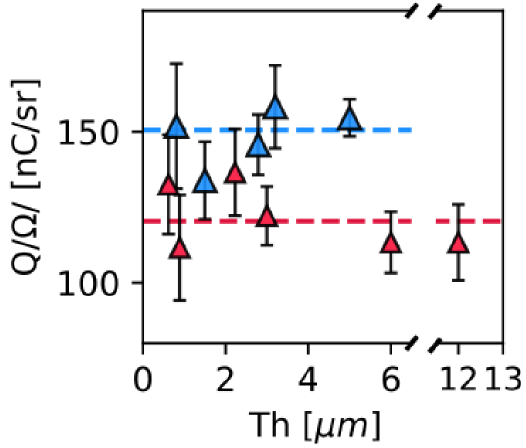
Maximum Energy
(Time-of-Flight)



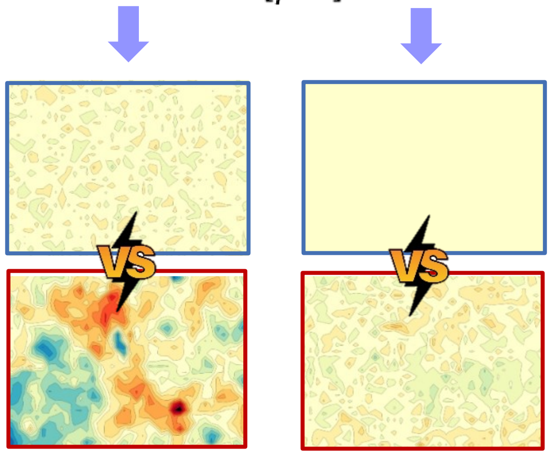
Ratio between uncertainties
(Deposited/Commercial)



Accelerated proton
charge



- Same $\mathbf{E_{Max}}$ **trend** for **deposited** and **commercial** foils, peaked @ ~ 3 μm **target thickness**.
  - < 3 μm → Pre-expansion of rear surface
  - > 3 μm → Weaker sheath field

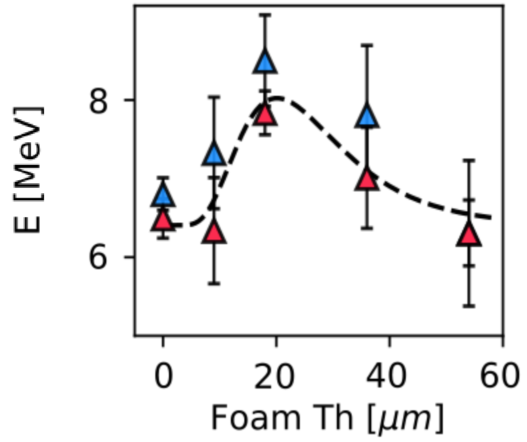


- 30 % more protons with **deposited** targets

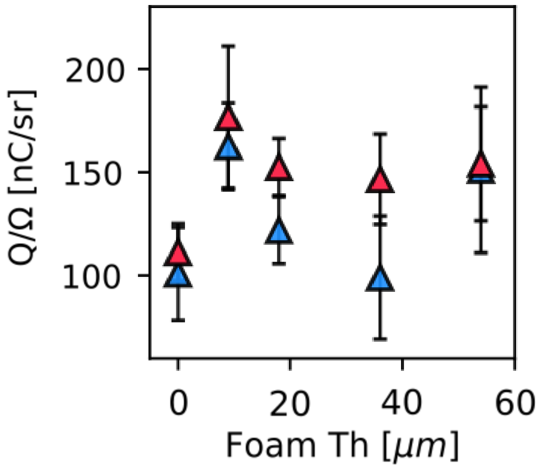
- Uncertainty on maximum energies lower with deposited targets

Proton acceleration from Double-Layer Targets

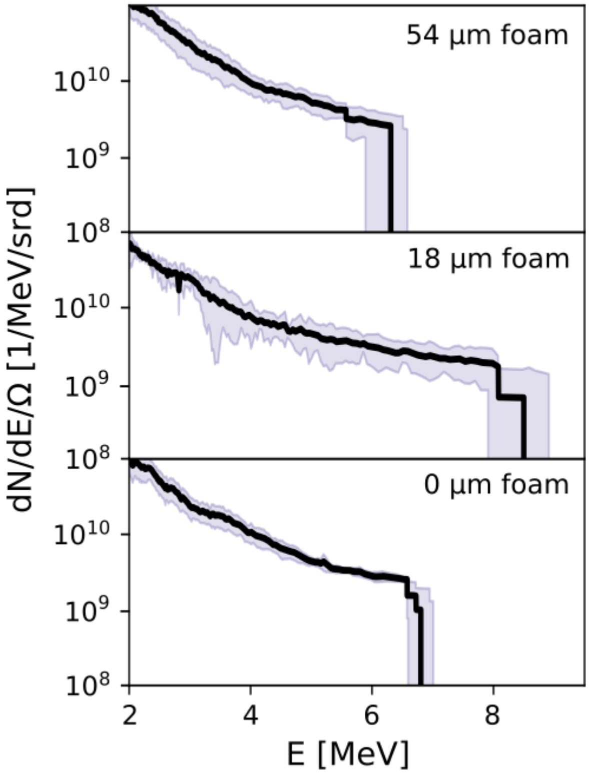
Maximum Energy
(Thomson Parabola)



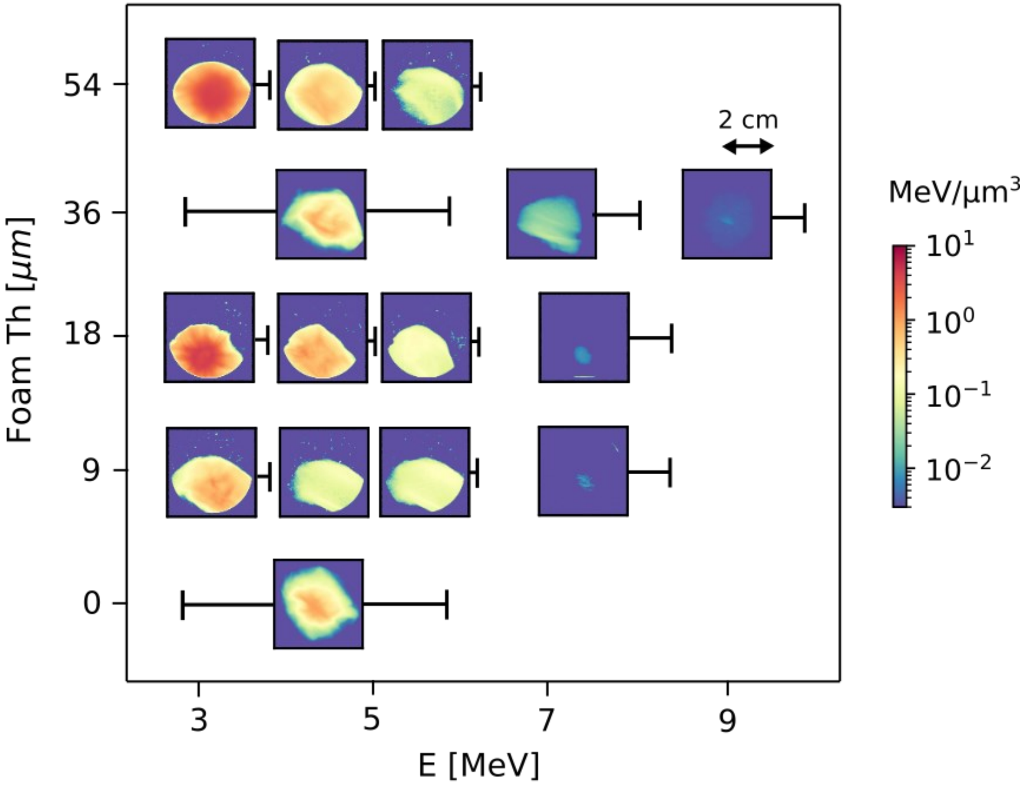
Accelerated proton charge



Energy spectra (Thomson Parabola)
for DLTs with 1.6 μm substrate



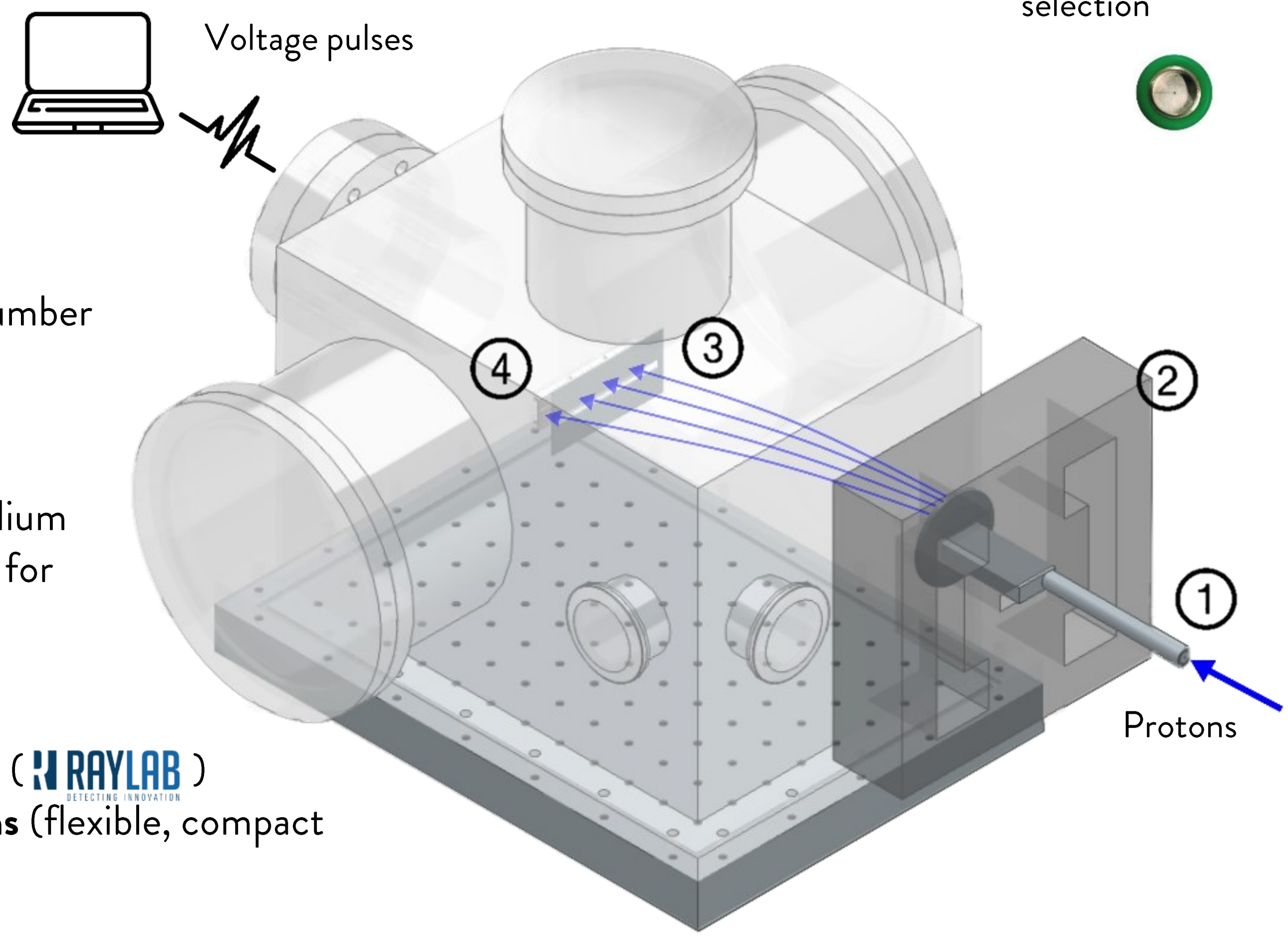
Energy deposited in RCFs for
DLTs with 1.6 μm substrate



- Same **E_{Max} trend** for DLTs with **deposited** and **commercial** substrates, peaked @ ~ 18 - 36 μm **foam thickness.**
- About **~ 2 MeV energy gain** with DLTs and ~70% more protons.

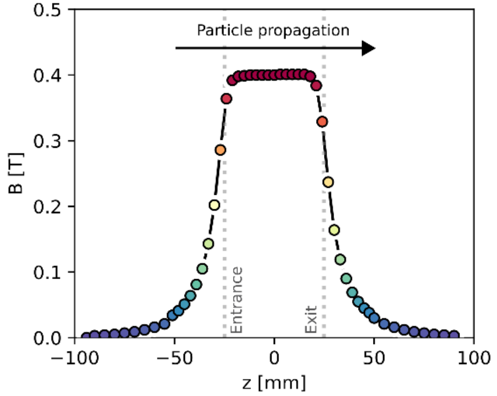
Spectrometer for proton characterization and applications

- Provide the proton **spectra online.**
- **Absolute calibration** → Number of accelerated particle.
- High resolution at low-medium energy → Most of protons for materials characterization.
- Future commercial product (RAYLAB) **oriented toward applications** (flexible, compact and reliable).



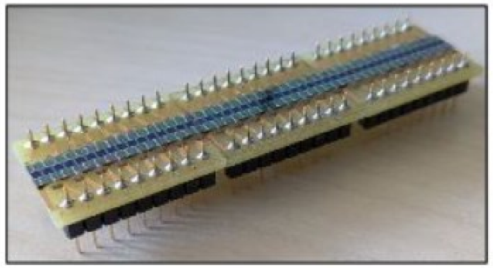
1 Pin-hole for proton selection

2 **Magnet** to deflect protons



3 **Multilayer stopper** to remove C-ions

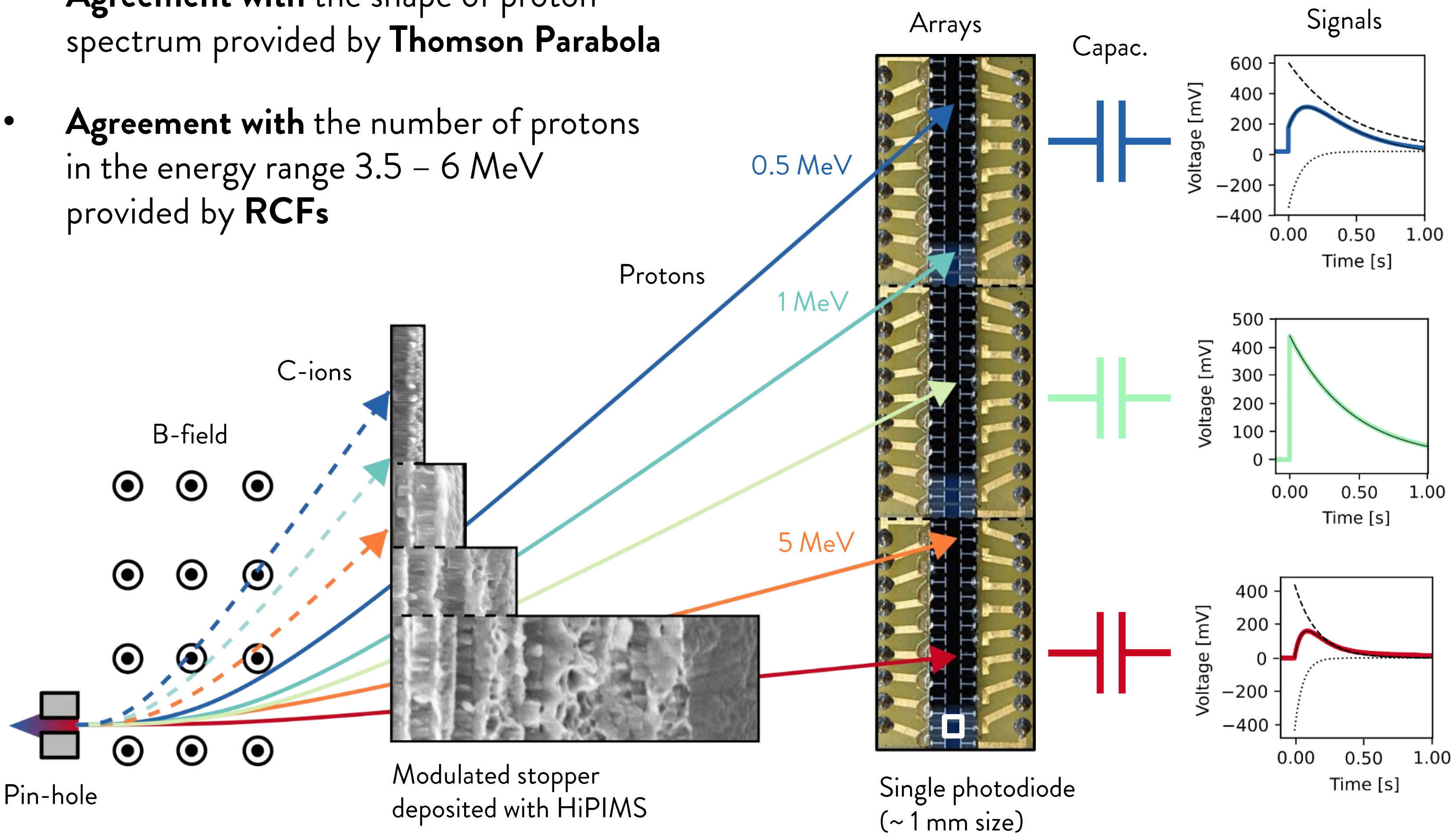
4 Silicon **photodiode array** for proton detection

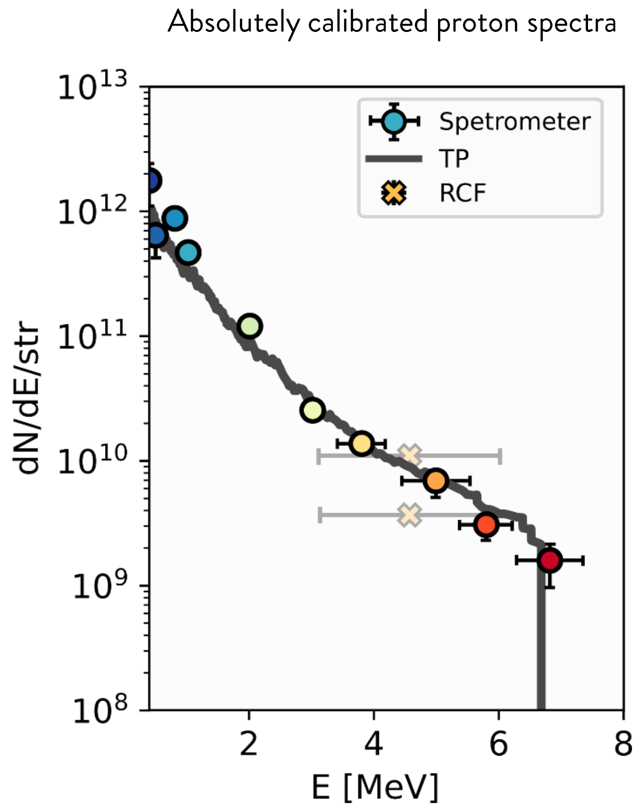


F. Casamichiela. *MS Thesis (2019).*
F. Gatti, et al. *IEEE Trans Instrum Meas, Under review.*

Spectrometer for proton characterization and applications

- We used for the first time the prototype during the campaign
- **Agreement with** the shape of proton spectrum provided by **Thomson Parabola**
- **Agreement with** the number of protons in the energy range 3.5 – 6 MeV provided by **RCFs**

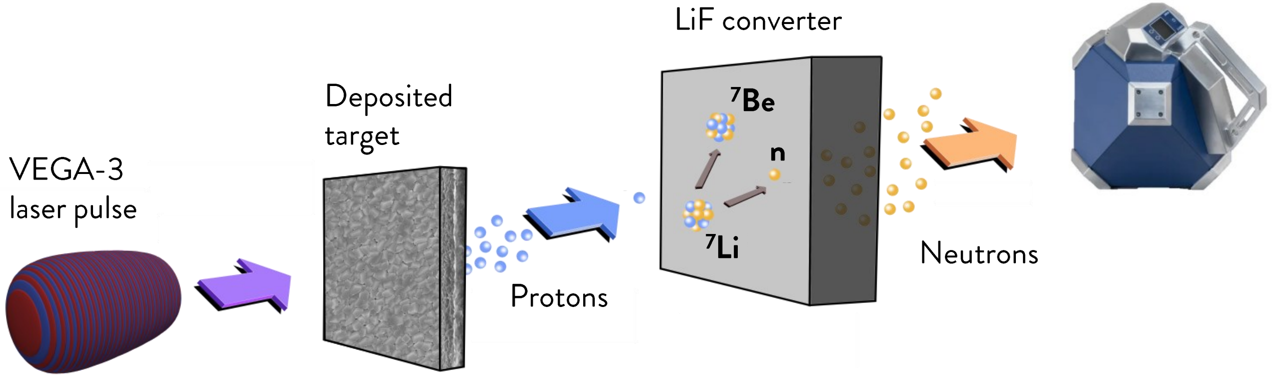




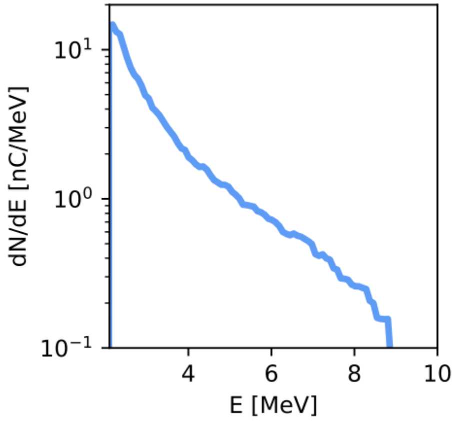
F. Gatti, et al. *IEEE Trans Instrum Meas, Under review.*

Test DIAMON real-real time monitor with laser-driven neutrons

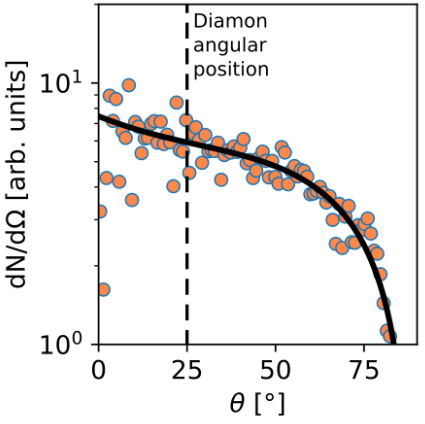
- Neutrons generated with a **Pitcher-Catcher** configuration.



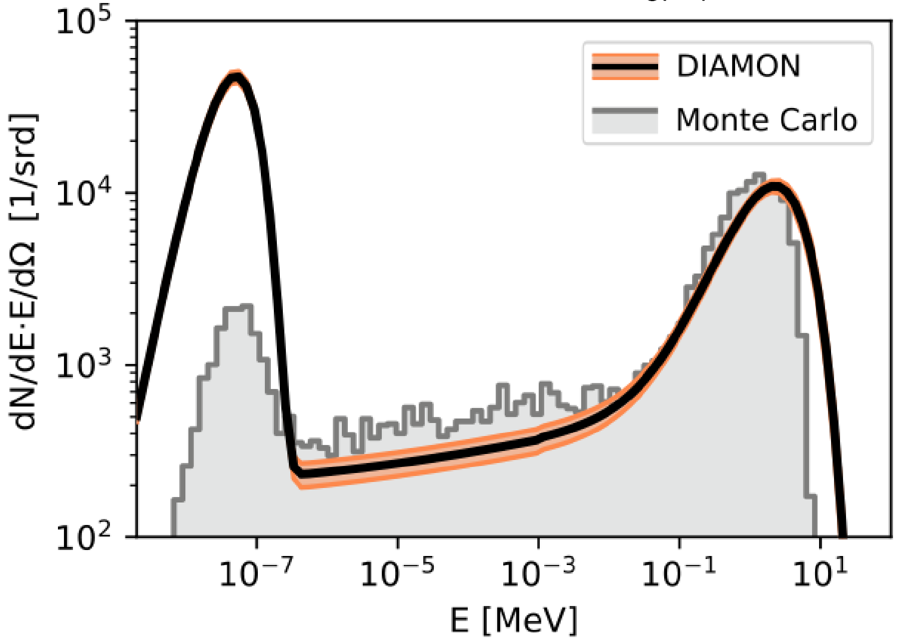
Proton spectrum (Thomson Parabola)



Neutron Angular distribution
(Monte Carlo)



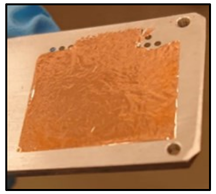
Simulated and detected lethargy spectrum



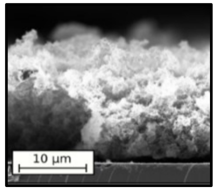
- **Epithermal** and **Fast** component → **Good** qualitative and quantitative **agreement** with GEANT4 **simulated** spectrum.
- ~3 × 10^4 fast neutrons/steradians
- Simulation underestimates thermal neutrons (just few elements in the experimental hall included)

A. Pola, et al. *Nucl. Instrum. Methods Phys. Res.* A 969 (2020): 164078.

Conclusions and perspectives

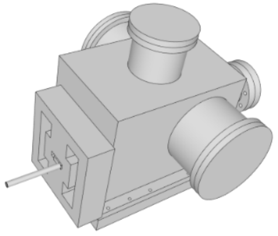


- HiPIMS deposited targets can provide **better** performances in terms of **shot-to-shot stability** compared with commercial foil.
- **Accurate characterization** is required when working with **sub-micrometric commercial targets**.



- While **Carbon-foams** provide an **enhancement for proton acceleration**, substrate properties must be considered.

…Hydrodynamic and Particle-In-Cell simulations study is ongoing…



- **Active diagnostics** based on Silicon sensors are **suitable tools to monitor online** multiple **laser-driven radiation** fields.
- One **DIAMON** detector is **currently @** CLPU for **future** laser-driven neutron characterization **campaigns**.
- An Experimental **campaign @** eli **beamlines** about **materials characterization** with laser-driven protons is scheduled in October → Plan to **use** both **deposited targets** and **updated** version of proton **spectrometer**.

Acknowledgments

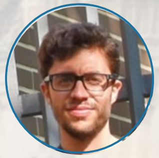
- Our group from POLITECNICO MILANO 1863

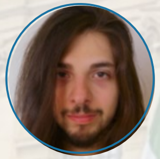

M. Passoni
Principal Investigator

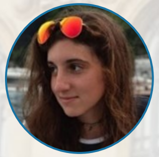

A. Maffini


F. Mirani


M. Galbiati


D. Vavassori


F. Gatti


S. De Magistris


K. Ambrogioni


D. Orecchia


D. Dellasega


V. Russo

- From RAYLAB DETECTING INNOVATION


D. Rastelli

- Activities part of an ERC-PoC project erc ERC-2022-PoC No. 101069171 **PANTANI**

- The team from ICTS Infraestructuras Científicas y Técnicas Singulares CLPU CENTRO DE LÁSERES PULSADOS

- The internal supervisors of the experiment


J. L. Henares


A. Morabito

- **The director, all-other researchers and administrative staff!**

- The initiative Laserlab Europe

Thank you for the attention!

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