POLITECNICO MILANO 1863

ELISS2023 Extreme Light Infrastructure Summer School

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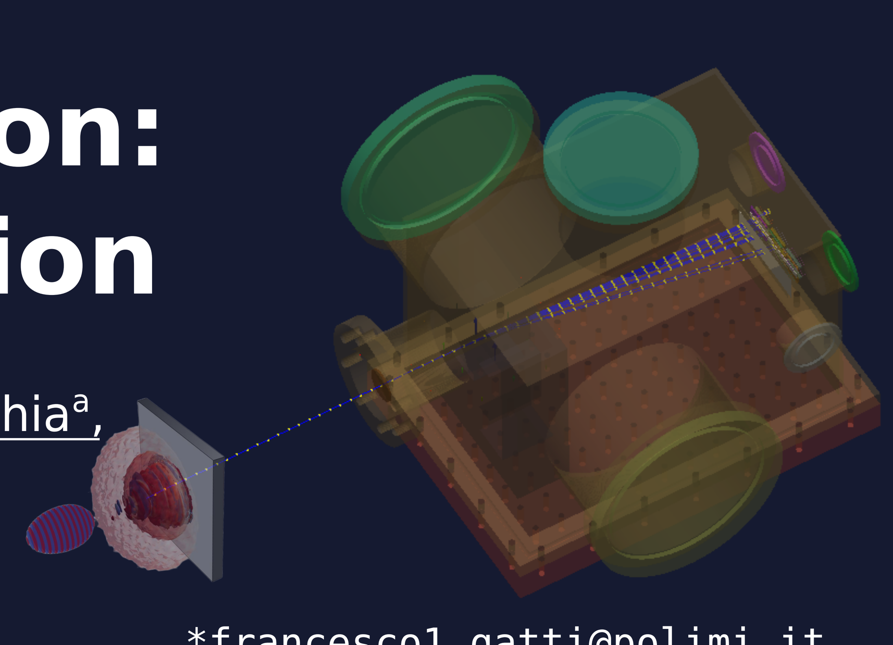
ELI Beamlines Facility
Dolni Břežany, Czech Republic

Laser - plasma proton acceleration: target production & particle detection



F. Gatti[a]*, F. Mirani[a], M.S. Galli de Magistris[a], D. Rastelli[b], A. Pola[a], D. Vavassori[a], D. Orecchia[a], A. Maffini[a], D. Dellasega[a], and M. Passoni[a]

[a]Department of Energy, Politecnico di Milano, Milano, Italy
[b]Raylab s.r.l., Via Monte di Pietà 2, 24043 Caravaggio (Bergamo), Italy

*francesco1.gatti@polimi.it

Context and motivation

Ion acceleration

- **Short laser pulses** (10s fs) with **relativistic intensities** (10^{18}-10^{22} W/cm^2)

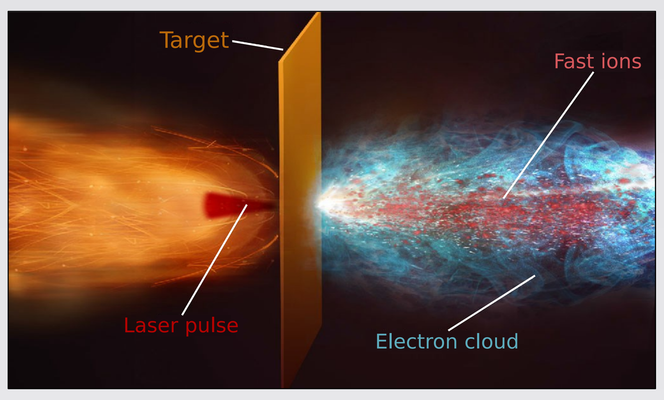
$$a_0 = \frac{eE_0}{m_e \omega_0 c} > 1$$

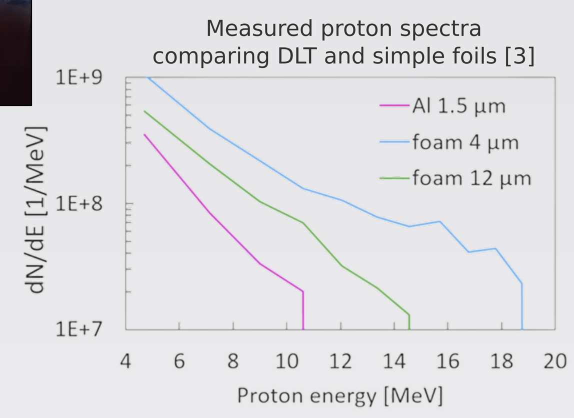
- Interaction with micrometric **solid foils**: Target Norma Sheat Acceleration (**TNSA**)
- **Plasma** generation: overdense regime $n_e > n_c$

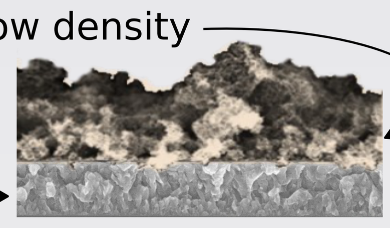
$$n_c = \frac{m_e \omega_0^2 \epsilon_0}{e^2}$$

- **Acceleration** of high energy **e**$^-$ and **ions**: 1-10s MeV [1]
- **Enhanced TNSA** [2]: addition of **near-critical** material $n_e \approx n_c$
  - ⟶ **Double Layer Targets** (**DLTs**): few µm solid + ~10 µm low density
  - ⟶ **Volumetric** laser-plasma interaction
  - ⟶ Density: **few mg/cm³**

- **Control** and improve **energy and number of particles** [3]
- Potential **compact and flexible sources**
  - ⟶ Application in **materials science** (e.g. PIXE [4, 5]), **radioisotopes** production, ...



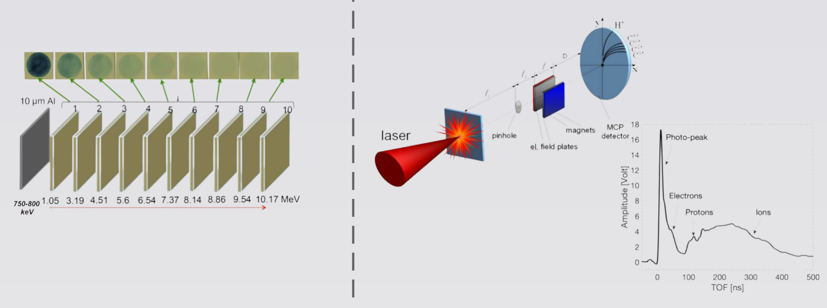




Ion detection

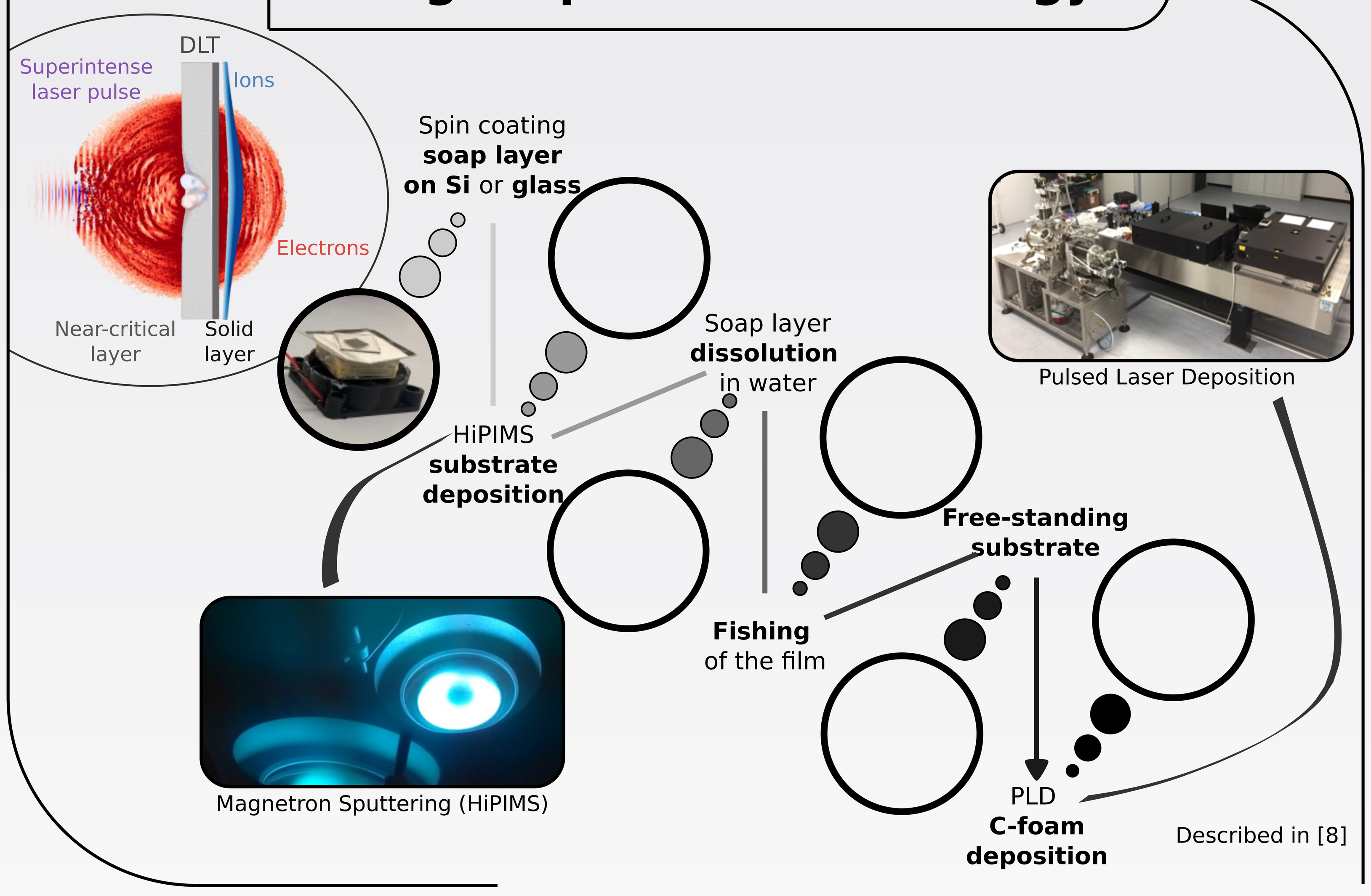
- Particle source diagnostic relies on [6, 7]:

Passive | **Active**



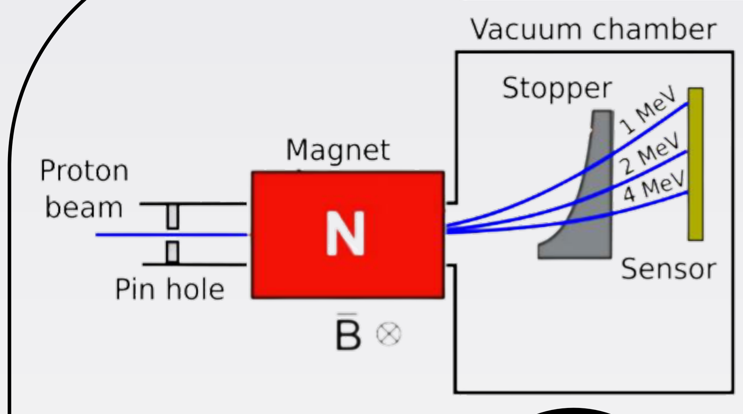
- Some relevant chracteristics and limits:
  - **Offline/online** data analysis
  - Dynamic **range** and saturation
  - Energy **resolution**
  - Info on **angular distribution**
  - **Absolute calibration**
  - **Discriminating** different particles

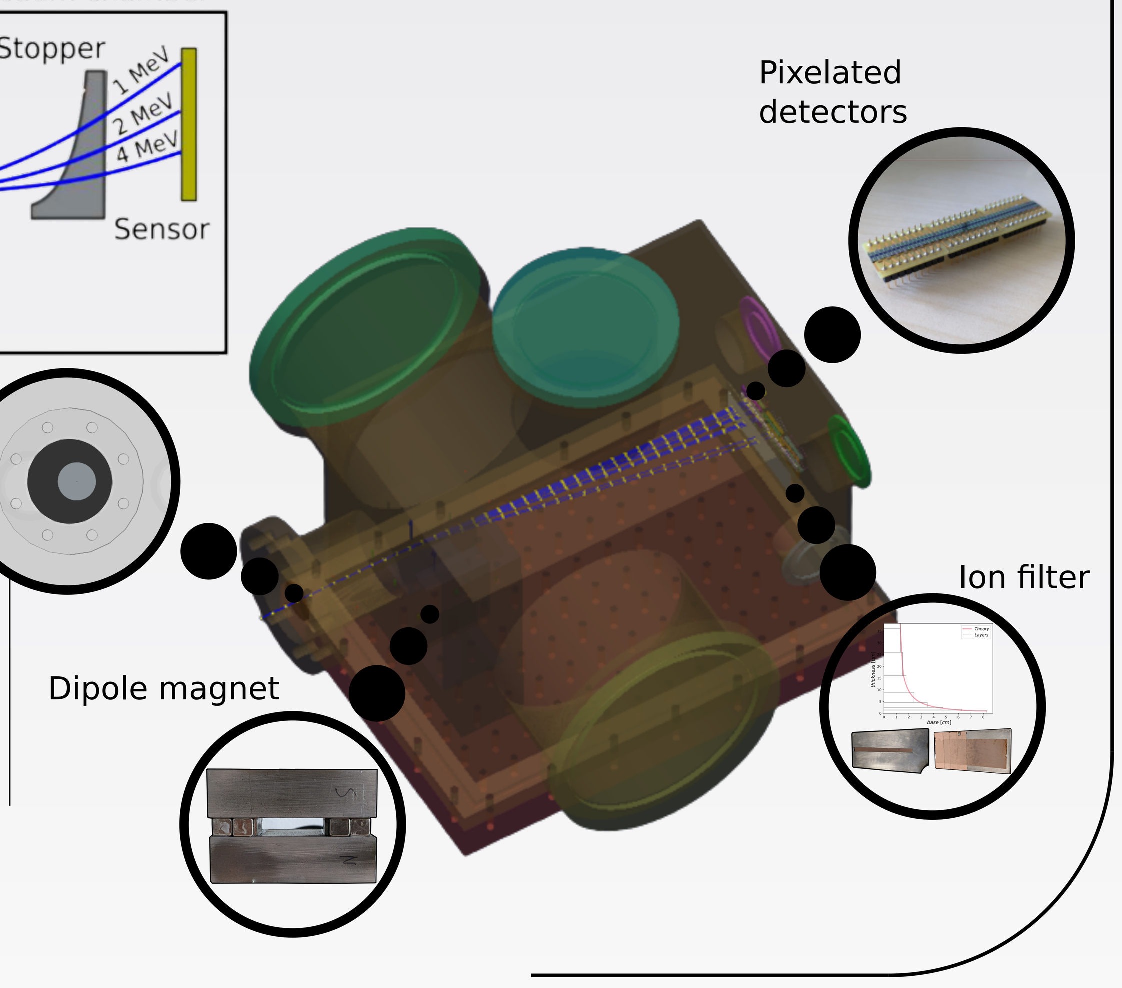
Targets production strategy



Described in [8]

Spectrometer concept

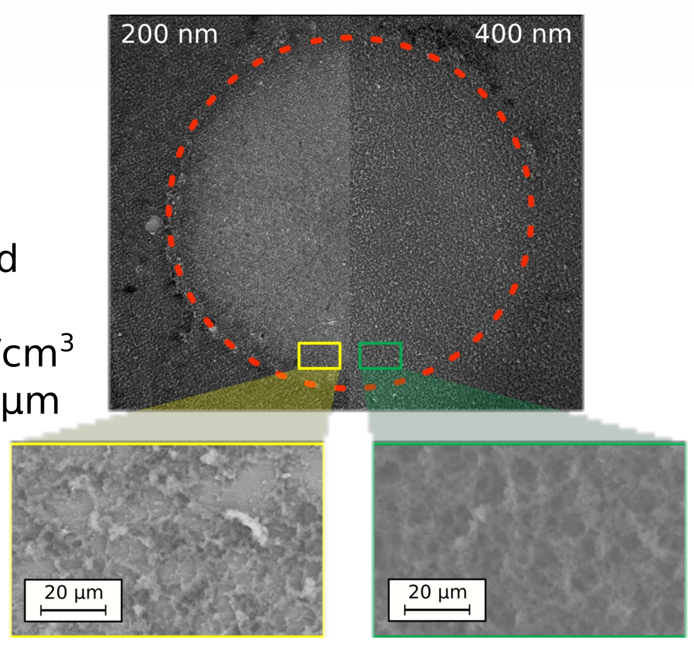




- Particles enter passing through the pinhole
- The magnet spreads ions according to their energy
- The filter selects protons by stopping heavier ions
- Semiconductor arrays collect the signals

Double Layer Targets

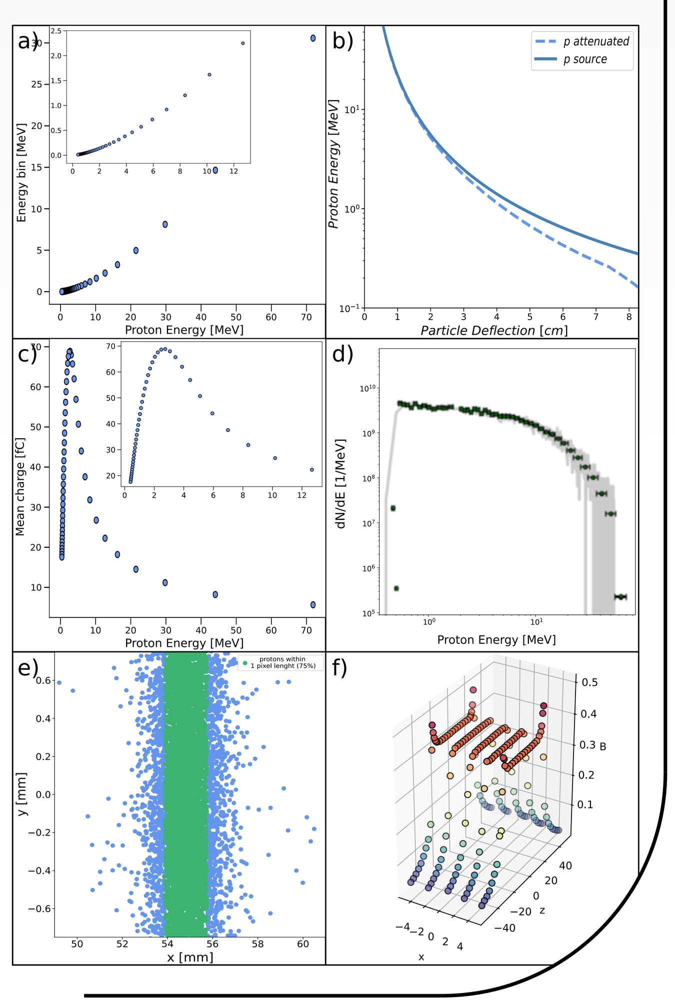
- **Solid** density **substrates** of **different materials** (Al, Cu, Ti) produced with DCMS and/or HiPIMS
- **Thickness** range for **free-standing** films **50 nm - 2 µm** with low uncertainty (~5 %)
- **Low residual stresses** and good integrity



- Carbon foam depodited with PLD with good control on [2]
  - **density** ⟶ from bulk to ~6 mg/cm³
  - **thickness** ⟶ from few µm to 10s µm
- On **thinner** free-standing **substrates** (<300 nm), **vibrational effects** cause partial **detachment** of C aggregates

Detector design and modeling

- Total size **< 30 cm**, with **5 cm, 0.4 T** magnet
- Energy range and resolution: **0.40±0.01** - 72±15 MeV (Fig. a-b) Reference value: **10.2±0.8** MeV
- Differential **filter**: **Cu + Cr + Al**, deposited with **DCMS** + commercial foils (~15 µm)
  - ⟶ **Particle discrimintation**
- Detectors' **pixels** ~2 mm^2, Charge Collection Efficiency (**CCE**) **experimentally characterized** (Fig. c), **current mode**
  - ⟶ **Real time**
- Monte Carlo gives **response matrix** (Fig. d)
  - ⟶ **Absolute calibration** (MeV^{-1}Sr^{-1})
- Proton **scattering** due to filter: > 70% (1 MeV) and > 98 % (10 MeV) of particles are **spread within** 1 **pixel** (Fig. e)
- Magnet field experimental map + test at accelerator (Fig. f)



Conclusions and perspective

- **Optimized Double Layer Targets** can be produced **combinig HiPIMS/DCMS and PLD** techniques
- Tuning **DLTs thicknesses and density**, the **characteristics** of **accelerated particles** can be controlled (role of **nanostructure**)
- The proposed **spectrometer** is a promising device to **characterize** laser-driven **protons** in **real time** with **absolute calibration**
- **Theoretical modelling** and **first experimental characterization** of magnet, differential filter and sesors paved the way for **use in laser-driven experiments**

- Extensive **Monte Carlo** simulations to be performed to build the response matrix
- The ad-hoc **front-end electronics** have to be tested
- The device will be tested at an **electrostatic accelerator** (Oct-Dec 23 @ LNL)
- The DLTs and the spectrometer will be used in **PW-laser** experiments @ CLPU in Nov 23

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