Diagnostic of Laser-Accelerated MeV Proton Beams from Near Critical Density Foam Targets Using Nuclear Activation Technique and Radiochromic Film Imaging Spectroscopy

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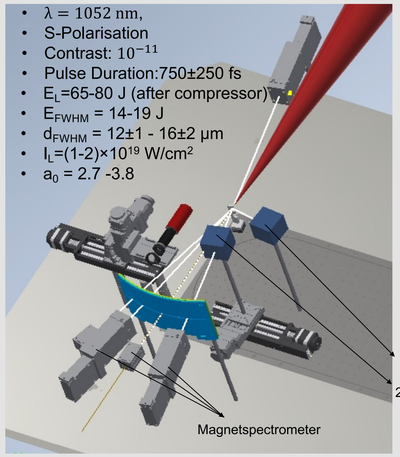
Abstract

To enhance the proton acceleration from interaction of high intensity short-pulse laser with plasma, we have performed an experiment using near-critical density (NCD) foam targets stacked with metallic foils [1, 2].
Two different methods, namely Nuclear Activation Technique and Radiochromic Film Imaging Spectroscopy were combined to characterize the proton beam. In the former a multilayer detector of thin metallic foils with different energy thresholds for (p,xn)- reaction allows for reconstruction of proton spectral distribution over a wide range of energy. It was experimentally verified that the application of foam targets increases the number and cut-off energy of laser accelerated protons in comparison of thin metallic Targets.
Foam Targets stacked with thick high Z converter generated high energy Bremsstrahlung (E>45 MeV), which was verified by the $^{181}_{73}Ta(\gamma,5n)$-reaction.
In addition, backward proton acceleration in NCD foams with a cut off energy of 15 MeV was demonstrated.

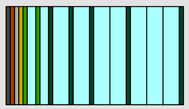
Experimental Setup

PHELIX-Laser Parameters:

- $\lambda = 1052$ nm,
- S-Polarisation
- Contrast: 10^{-11}
- Pulse Duration:750±250 fs
- E_L=65-80 J (after compressor)
- E_{FWHM} = 14-19 J
- d_{FWHM} = 12±1 - 16±2 µm
- I_L=(1-2)×10^{19} W/cm²
- a_0 = 2.7 -3.8



Structure of a Stack Diagnostic



V-Cu-Ti-Au
EBT-3
HD-V2
Mylar film

1. RCF-Box (-10°, 8 cm)
2. RCF-Box (-95°, 8 cm)

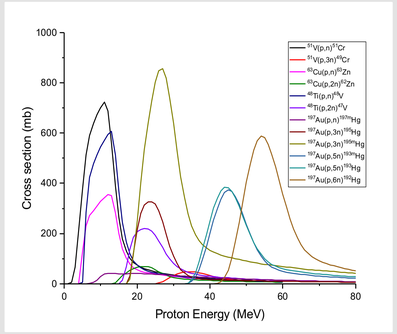
Methodology of Nuclear Activation

The number of reactions, N, induced by protons is:

$$N = N_0 \int_{E_{th}}^{\infty} \sigma(E) \cdot n_p(E) dE$$

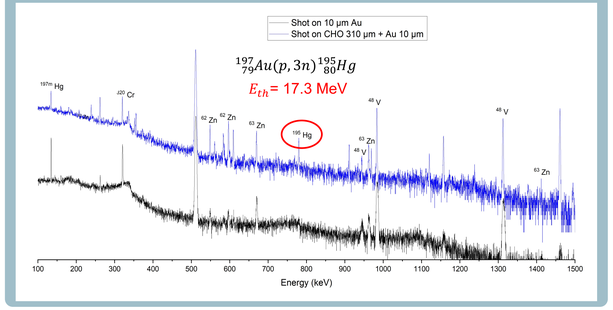
N_0: Total number of irradiated nuclei
E_{th}: Threshhold energy of reaction
$\sigma(E)$: Reaction cross section
$n_p(E)$: Incident proton energy distibution per area

Overview of cross section of selected nuclear reactions



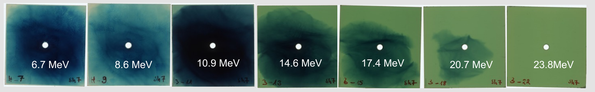
Comparison of Gammaspectrum of a shot to Foam+Foil Target with Foil Target

- The γ-line of $^{197}_{79}Au(p,3n)$-reaction only visible on shot on Foam+foil Target



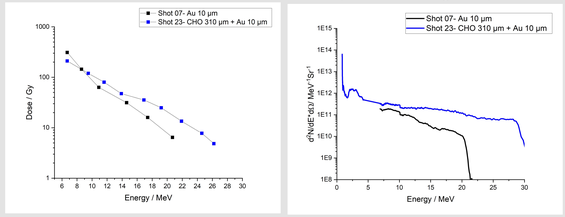
Results of Radiochromic Films

Shot on 10 µm Au: 79.9 J (17.2 J, 1.3x10^{19} W/cm²)

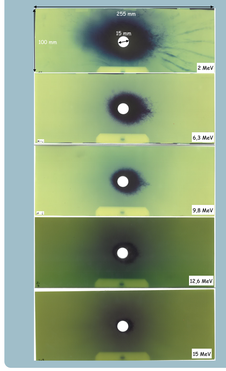


Shot on CHO 310 µm + Au 10 µm : 65.9 J (17 J, 1.7x10^{19} W/cm²); ~ 0.3%, delay 3 ns

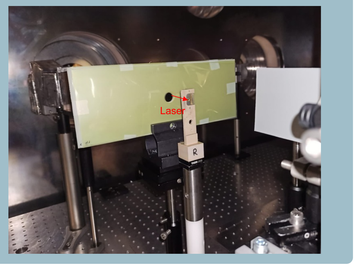
Protonspectra from Magenetspectrometer



Backward Ion Acceleration

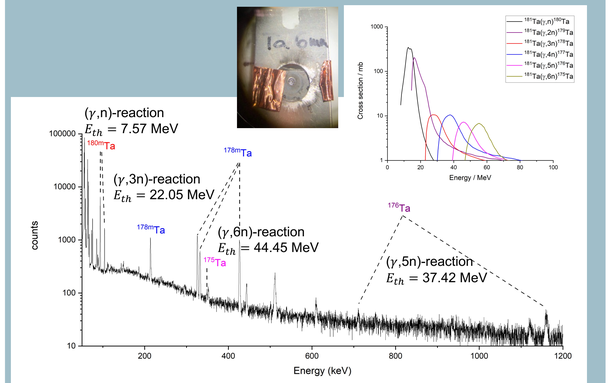


	Cut-off energy/ MeV	Laser intensity / W cm^{-2}
This Experiment	18	$3 \cdot 10^{19}$
Habara, et al. [3]	15	~$2 \cdot 10^{19}$



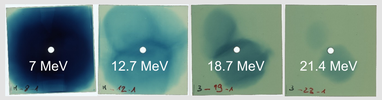
Effective Generation of bremsstrahlung with E> 45 MeV

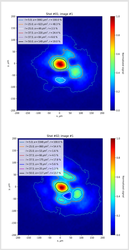
Shot on CHO 1000 μm + 6mm Ta: 70.0 J (2x10^{19} W/cm²)



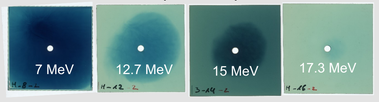
Energy deposition smoothing using Foams

Shot on 10 μm Pb: 80.3 J





Shot on CHO 460 μm+ 10 μm Pb : 66.1 J



References

[1] Rosmej, O. N., et al. "Interaction of relativistically intense laser pulses with long-scale near critical plasmas for optimization of laser based sources of MeV electrons and gamma-rays." *New Journal of Physics* 21.4 (2019): 043044.
[2] Günther, M. M., et al. "Forward-looking insights in laser-generated ultra-intense γ-ray and neutron sources for nuclear application and science." *Nature Communications* 13.1 (2022): 1-13.
[3] Habara, Hideaki, et al. "Backward-ion acceleration in critical density plasmas." (2021).