Enhancing light-matter interaction with nanostructured targets

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Abstract

In the high-power laser-matter interaction, two main components are the laser pulse and the target. By adjusting one of them, the results can be tailored to a specific application. Nano and micro structured targets are being studied for applications of high intensity laser-matter interaction for more than 30 years [1] and take many forms: gratings, wires, dots, spheres, tubes. With the help of these targets, we can modify the laser interaction to improve the particle acceleration, by increasing the surface area and through volumetric heating [2], resulting in higher proton energies [3] or increased X-ray flux, high energy density matter creation and terabar pressures [4].

Metallic (gold and nickel) nanowires and nanotubes were fabricated in the Target Laboratory from ELI-NP by electrochemical methods, using porous alumina as a template [5]. These targets were used in 1 PW laser experiment to study the x-ray emission and proton acceleration, with an experimental set-up employing a single plasma mirror for contrast enhancement, and for diagnostics: radiochromic films (RCF) and Thompson parabola (TP) for ion detection, and CsI scintillators for photon detectors. Proton and ion results, as well as photon and electron signals will be presented from the nanostructured targets, in comparison to flat targets.

Motivation

High energy density matter +Tbar pressure

C. Bargsten et al., Science Advances, 2017
J.F. Ong et al., Phys. Rev. E, 2023

Synchrotron radiation X-ray source

A. Andriyash et al., Nature Comm, 2014

Proton acceleration

S. Vallieres et al, Nature Scientific Reports, 2021

Micro-scale fusion

A. Curtis et al, Nature Comm, 2018

Nanostructured targets in laser experiments may increase:

- ✓ **Maximum resulted particle energy**
- ✓ **Volumetric heating**
- ✓ **Laser absorption on the target**
- ✓ **Conversion efficiency**
- ✓ **Xray emission**

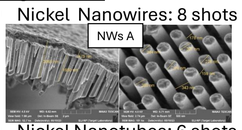
Methods

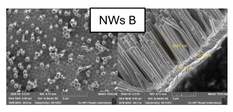
I. Nanostructured targets

➢ Grown by electrochemical methods

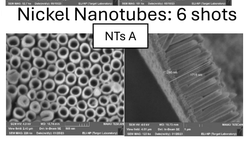
Targets shot:

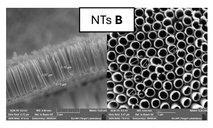
- Nickel Nanowires: 8 shots

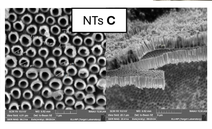


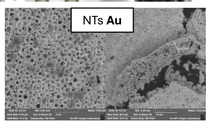


- Nickel Nanotubes: 6 shots





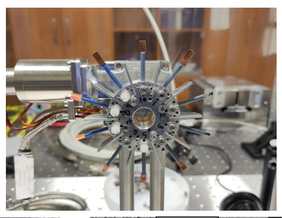




- Gold Nanostructured target: 1 shot
- Flat nickel for comparison (6 shots) - same as substrate (1 μm)
  - total target thickness (2.5 μm)

Total: 21 targets shot

C. Gheorghiu et al., Frontiers in Physics, 2021
S. Ionescu et al., submitted to Discover Nano



Tabel 1. Target parameters

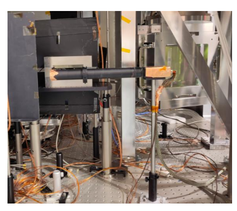
Type	Diameter, nm	Interval, nm	Length, μm	Substrate, μm
NWs A	300	200	2.5	0.5
NWs B	200	2-300	4	0.5
NTs A	200	50	1.3	0.3
NTs B	450	50	2.4	0.1
NTs C	400	100	2.2	-
NTs Au	300	100	5	-

Diagnostics

- Thompson Parabola (TP) with image plate (IP)
- RCF (radiochromic film stack- 2D proton distribution)
- 2 CsI scintillators stack and CCD cameras
- bubble detectors, ionization chambers
- laser diagnostics (NF, FF, FROG)

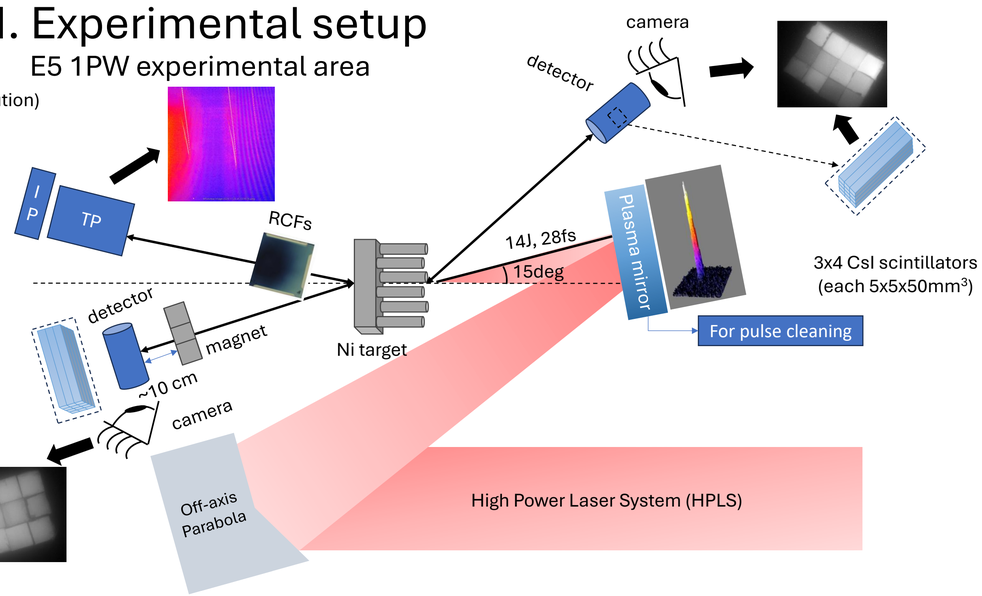
Thompson Parabola parameters:

- 200 μm pinhole
- 12 kV voltage
- 1 T magnetic field
- 70mm magnet length



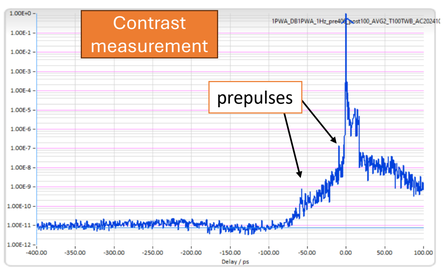
II. Experimental setup

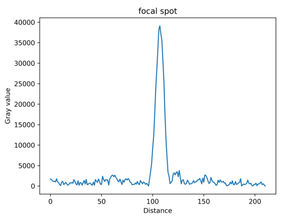
E5 1PW experimental area

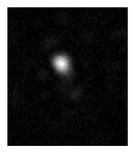


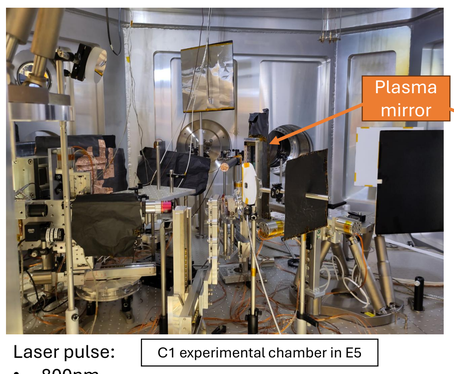
Results

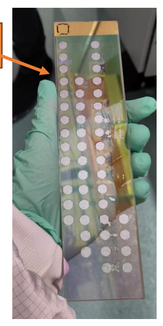
A. Laser pulse characteristics









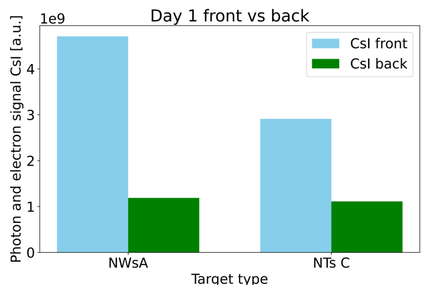


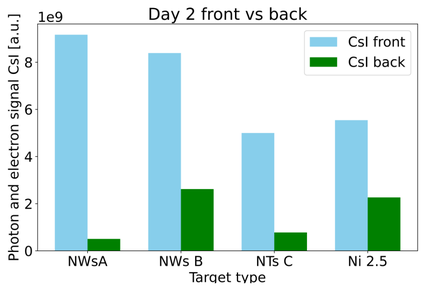
Laser pulse: C1 experimental chamber in E5

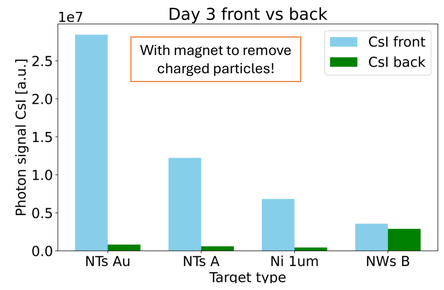
- 800nm
- 30 J*0.69(after compression and OAP)* 0.6 (PM reflectivity)= = 12 J on target
- 23-24 fs
- 3.8 μm²
- p polarization

→ $3x10^{21}$ W/cm²
a_0=37

B. Photon and electron signal



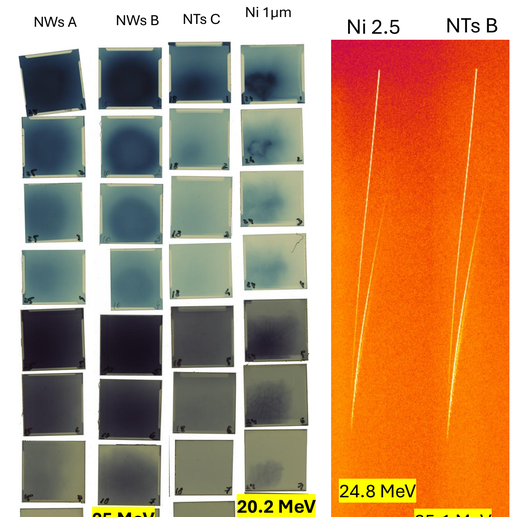




➢ Higher photon and electron signal from nanowires compared with nanotubes
➢ Double photon signal for NTs A vs Ni 1um,
➢ and factor of 4 from gold nanotubes

C. RCF and TP results – proton diagnostics

Raw Data



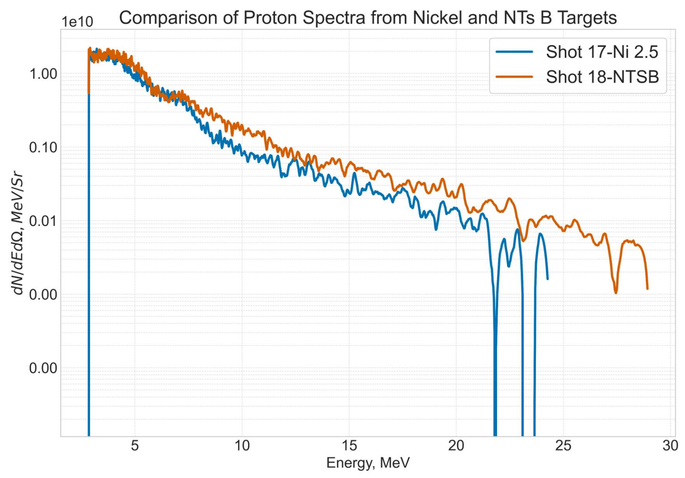
Tabel 2. Experimental proton cut-off energy, averaged per shots

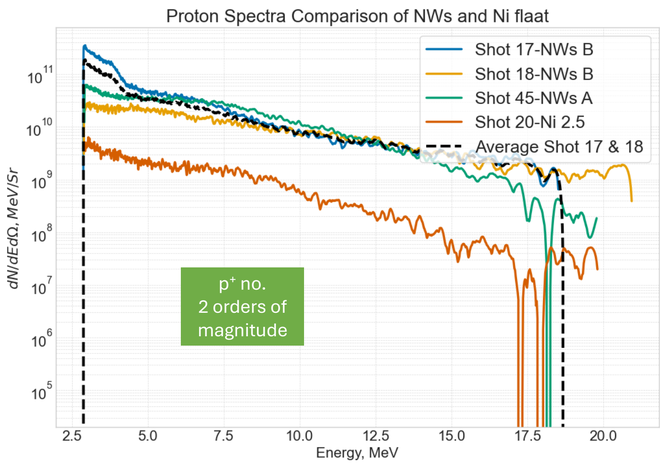
Target type	RCF, proton cut-off energy, MeV	TP, proton cut-off energy, MeV
NWs A	26	16
NWs B	20.2	18.5
NTs Au	25	
NTs A	25	
NTs B		27.5
NTs C	17.4	17
Ni 2.5 μm	37.2	20.25
Ni 1 μm	20.2	

Findings:

- ➢ Highest on RCF from NWs A and B (and Ni 2.5μm)
- ➢ Highest on TP from NTs B
- ➢ Ring-like beam shaping on RCF from nanostrutures

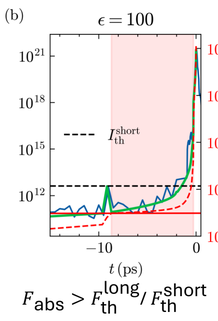
Experimental TP proton spectra





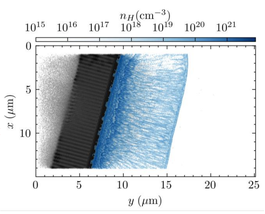
PIC simulations

Laser Contrast Improvement after the plasma mirror



Contrast improvement factor

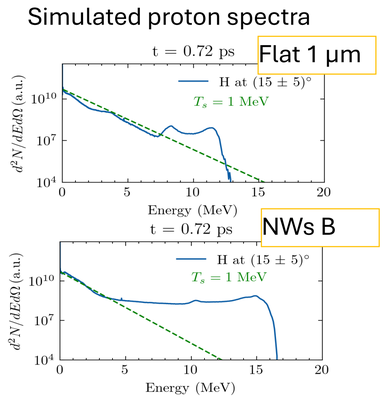
$\epsilon = 100$



$F_{abs} > F_{th}^{long} / F_{th}^{short}$

Region of hydrodynamic simulation

Simulated proton spectra



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2. Hill, M. et.al. "Volumetric heating of nanowire arrays to keV temperatures using kilojoule-scale petawatt laser interactions", arXiv:2007.10410v1 (2020)
3. S. Vallieres et al., "Enhanced laser-driven proton acceleration using nanowire targets," Scientific Reports 11, 2226 (2021)
4. C. Bargsten, "Energy penetration into arrays of aligned nanowires irradiated with relativistic intensities: Scaling to terabar pressures," Science Advances 3.1, e1601558 (2017).
5. C. Gheorghiu et.al., "Structuring Free-Standing Foils for Laser-Driven Particle Acceleration Experiments", Frontiers in Physics (2021)

Conclusions and perspectives

- ✓ Improved interaction from tailored nanowires and nanotubes targets by:
  - ✓ Dependencies of proton yield and cut-off energy from different target configurations observed;
  - ✓ Higher photon signal (from nanowires and gold nanotubes);
  - ➢ To continue data analysis and correlation with laser properties;
- ✓ Very good laser stability (energy, shape and pointing);
- ✓ No back-reflection measured;
- ✓ Simulations in accordance with experimental data – to continue with other target configurations;
- ➢ Statistics needed

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